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QUANTIFYING PRODUCTIVITY LOSS DUE TO FIELD DISRUPTIONS IN MASONRY CONSTRUCTION

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QUANTIFYING PRODUCTIVITY LOSS DUE TO FIELD DISRUPTIONS IN MASONRY CONSTRUCTION

by

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Dissertation

Presented to the Faculty of the Graduate School of

The University of Texas at Austin

in Partial Fulfillment

of the Requirements

for the Degree of

Doctor of Philosophy

The University of Texas at Austin
December, 2001

To my parents and my brothers and sisters
for their love, support, and encouragement.

ACKNOWLEDGEMENTS

I would like to express my appreciation to the members of my advisory committee for their direction and guidance. My special thanks are extended to my supervising professor, Dr. Calin M. Popescu, who has been extremely helpful and supportive throughout the study. I am very grateful for his advice and personal concern for the study. His encouragement and the confidence he placed in me during the study made the task a lot more enjoyable. I would also like to thank Dr. John D. Borcherding for his guidance in developing the questionnaires and supervising the subject matter. His willingness to share his time and profound insight into the subject matter contributed to making this study a positive learning experience.

I am grateful to Dr. G. Edward Gibson, Jr., for his support and assistance in this research effort. His helpful discussions and comments on the study are gratefully acknowledged. I would also like to thank Dr. Stephen R. Thomas for his time and guidance in the research survey. His expertise and understanding of research surveys made working with him a genuine delight. Additionally, I wish to acknowledge Dr. Daniel A. Powers for his guidance in supervising the statistical analysis procedures. His valuable time and helpful comments are greatly appreciated.

Special thanks also go to Mr. Jeff Buczkiewicz, Director of Marketing for Mason Contractors Association of America, who distributed and collected the questionnaires, which played an important role in the success of the study. Appreciation is also extended to Mr. Jim Crook and Mr. Chuck Pollard, Resident Construction Managers of the Office of Facilities Planning and Construction at the University of Texas at Austin, for their support and assistance in facilitating the model validation process. Without their support, this research could not have been successfully accomplished.

I would also like to thank Mr. Kan Phaobunjong, Ms. Eunhee Kim, Mr. Unsuk Jung, Mr. Hyoungkwan Kim, Mr. Yu-Ren Wang, and other friends in the CEPM program, who were willing to take a little time to listen whenever I had anything to say. Further thanks go out to Dr. Thanachan Mahawanuch and Ms. Tattaya Hanbenjapong for their caring support and encouragement. Finally, I owe my deepest gratitude to my parents and my brothers and sisters for their never-ending love and encouragement throughout my graduate studies. Without their continued support and concern, I would never have succeeded in such an encompassing endeavor.

QUANTIFYING PRODUCTIVITY LOSS DUE TO FIELD DISRUPTIONS IN MASONRY CONSTRUCTION

Publication No. ______________

Nuntapong Ovararin, Ph.D.
The University of Texas at Austin, 2001

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Many research studies have proven that productivity loss is the result of several factors including excessive change orders, long periods of overtime, poor field management and severe weather. These factors generate further disruptions affecting masonry productivity, and result in productivity loss or additional work-hours to be required to perform masonry work. Unfortunately, estimators have had difficulties in quantifying this productivity loss because no data of normal productivity without an impact of field factors is available for determination of such loss. The quantitative evaluation of productivity loss due to field disruptions in masonry construction is therefore needed.

This research study presents a quantitative evaluation of productivity loss due to field disruptions, based on a national survey. This study is intended to be a reference tool for masonry practitioners in construction claims, construction estimating, planning and scheduling. The primary objective of this study was to quantify productivity loss caused by sixteen different field disruptions based on three levels of standard field conditions for masonry building construction. With respect to this objective, a model used to estimate productivity loss or additional work-hours due to the impact of field disruptions was developed, based on a national survey conducted in the year 2000. A total of 950 questionnaires were randomly distributed to masonry contractors throughout the U.S., and 152 questionnaires were collected. The model presents an averaged percentage of productivity loss due to field disruptions, along with a range of possible loss that may exist. Masonry practitioners can employ the results of this survey to determine additional work-hours needed to perform the masonry work in field conditions that differ from original expectations.

Through a second research survey, conducted in Texas, the model was tested using five masonry construction projects facing field disruptions. It was found that the differences in the estimated and actual percentages of productivity loss ranged from -2 to 19%. In this dissertation, research procedures, conclusions, and recommendations for industry and future research are also discussed.

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CHAPTER I

INTRODUCTION

In recent years, there have been numerous investigations involved with labor productivity in construction, some of which are related to the quantification of the impact of productivity factors. Quantitative evaluations of the effects of these factors are needed for many purposes including construction estimating, planning, scheduling, and proof of damages in construction claims. However, an extensive review of relevant literature reveals that it is difficult to quantify such an impact, and there are currently no universally accepted standards for quantifying productivity loss in the masonry construction industry. This lack of a means for quantification of impact highlights the need to enhance quantitative evaluations of productivity loss due to field disruptions in masonry building construction, which is the subject of this study.

1.1 Problem Statements

One of the most current serious problems facing the construction industry all over the United States (U.S.) is loss of productivity due to delays and disruptions of projects. Research studies have proven that productivity loss results from several causes including excessive change orders, long periods of overtime, poor field management and severe weather (Borcherding and Alarcon, 1991; Leonard, 1987;

Sanders and Thomas, 1991; Thomas and Oloufa, 1995). In fact, these factors typically generate further disruptions affecting productivity that are beyond the direct control of a contractor, and result in productivity loss or additional work-hours required to perform the work. Unfortunately, estimators have difficulty quantifying the impact of productivity loss because the period of normal productivity without the impact of field factors and the detailed cost accounting records necessary for determination of the additional costs generally are not available (Dieterle and DeStephanis, 1992). In addition, current construction contracts do not usually include sufficient language to identify compensation for productivity loss due to field factors (CII, 2000; NECA, 1989).

The quantitative evaluation of the effect of factors on construction productivity has been investigated by numerous researchers, construction managers, contractors and owners. Several attempts have been made to measure the effects of field factors but most studies focus on the effect of only a single field factor and the results of many studies have usually been based on a limited amount of data or provide an insufficient amount of data characteristics (Borcherding and Alarcon, 1991). Moreover, the information available is sometimes based on the judgment and experience of only a small number of construction personnel (Borcherding and Alarcon, 1991). And a construction expert is necessary to ensure the proper use of available information, thus limiting its use (Dieterle and DeStephanis, 1992). More importantly, inclusive information of the effect of field factors on construction productivity in general is not also available for masonry building construction in particular, even though the U.S. masonry is a large industry (Grimm, 1974). Advancements in the process of quantitative evaluation of productivity loss due to field disruptions in masonry construction are therefore needed.

1.2 Research Objectives

An extensive literature review reveals the need for quantitative evaluation of productivity loss due to field disruptions in construction. The primary purpose of this research study is to quantify productivity loss due to field disruptions based on standard conditions for masonry building construction. This can be accomplished by developing a user-friendly model to assist in estimating productivity loss due to field disruptions. The model needs to be quantitatively validated in terms of productivity loss so that it can be widely accepted in the masonry construction industry. This research, therefore, addresses these issues through the five research objectives described below.

1. *To identify productivity loss factors in the construction industry*: An extensive review of the relevant literature must be conducted to determine factors that can generate loss of productivity, as well as their causes and effects. Common field disruptions are to be listed and used for further analysis.

2. *To develop standard conditions of common field disruptions for masonry*: Standard conditions are needed as a basis for quantifying the effect of field

disruptions. Standards can facilitate the uniformity of data collection in a research survey and, more importantly, enhance future usage of the model. The standard conditions can also enable general contractors to be aware of field condition levels that might produce significant loss in masonry productivity.

3. *To present quantitative values of productivity loss based on statistical analysis, and compare the results with other studies*: The estimates of productivity loss due to field disruptions are to be investigated through a national survey. The results and the comparison allow estimators to generate a more defined and accurate estimate.

4. *To develop a model providing estimates of productivity loss due to the effects of field disruptions in masonry construction*: This model can be implemented as an estimating tool producing estimated loss of productivity and a possible range of productivity loss due to field disruptions based on the standard conditions previously developed.

5. *To validate the model with actual project data*: The model developed is intended to be a reliable estimating tool for productivity loss due to field disruptions. Therefore, a statistical analysis will be conducted to validate the accuracy of the model based on selected construction projects, which will be examined through survey interviews with several representatives from one owner organization and three masonry companies.

1.3 Research Hypothesis

The hypothesis of this research study is that there are statistically significant differences among productivity loss of different severity levels of field conditions in a masonry building construction project. The severity levels of field conditions refer to three different standard conditions: minor, moderate, and severe.

1.4 Research Scope and Limitations

This research study has examined 16 field factors that significantly affect masonry productivity in building construction. This study mainly focuses on disruptive factors that can occur in any construction project. These factors may result from various circumstances involving change orders, overtime, poor coordination, inadequate field management, interference with surrounding work activities, and weather and environment. Even though construction is dynamic and it is difficult to isolate one factor from others that may affect labor productivity (Schwartzkopf, 1995), this research study postulates that the impact of an isolated factor can be approximately estimated based on respondents' experience and judgment, and their database built from previous projects. The impact of multiple factors affecting a job at the same time can also be approximated using an additive approach.

In addition, this research study does not consider some aspects including project types, work types and design requirements. For example, the difference between high-rise building projects, which require an extensive use of scaffoldings, and low-rise building projects, which require little or no use of scaffoldings, is not considered. Additionally, there is no difference in factory building projects, which usually contain long straight walls with few openings, and residential building projects, which contain shorter walls with more openings. Differences in particular work types, for instance the difference between single-wythe masonry walls and cavity walls or different wall shapes, are also disregarded. Lastly, this study does not focus on the difference of bond types, types and sizes of masonry units, mortar joint and wall thickness, and types of mortar. This research study is therefore intended to be a reference, which may require modifications based on other sources including historical databases, other research studies, industry-wide studies or experts.

1.5 Dissertation Organization

This dissertation consists of seven chapters and appendices containing supporting information and results of the data collection and analysis. Following this introduction chapter, a comprehensive literature review with respect to labor productivity in construction from professional journals and texts is presented in Chapter Two. It begins with defining productivity and then examines loss of productivity, productivity and project performance, and various productivity factors. Chapter Three discusses the research methodology necessary to achieve the research objectives. Survey investigations along with statistical analysis tools were chosen as the optimum means for developing and validating the presented model, and these are discussed in Chapter Three.

Chapter Four discusses details of the survey package, including the 16 field disruptions and three levels of standard field conditions. This chapter also provides a descriptive analysis of the survey participation and associated projects, and the data screening process for the national survey investigation is also presented. Chapter Five reveals the research findings from the analysis of the national survey and presents discussions regarding findings of this research study, and compares them with the results of other studies. Chapter Six presents the model developed to estimate the impact of field disruptions and the model validation results based on case study investigations. This chapter also discusses validations of the research hypothesis. Chapter Seven reviews the achievement of research objectives as well as conclusions, recommendations, contributions, and suggestions for future research.

CHAPTER II

RESEARCH BACKGROUND

Evidence presented in a number of recent research studies in construction highlights the significance of productivity of the work force and its quantification. In attempting to measure productivity in construction, one is always faced with a vast array of productivity terminology, various arguments concerning productivity and project performance, and a number of productivity factors that occur within the construction process. With respect to these concerns, this chapter discusses background information regarding productivity, project performance in terms of productivity, and productivity factors involved in loss of productivity. The background information includes an introduction to various productivity definitions, aspects of loss of productivity, and productivity trends. The project performance presented herein refers to its major functions and their relationship to productivity. Causes and effects of various productivity factors that may result in loss of productivity are presented in the last part of this chapter.

2.1 Productivity Background and Definitions

2.1.1 Definition of Productivity

The term productivity is generally used to present a relationship between outputs and the corresponding inputs used in the production process (Liou and

Borcherding, 1986). In the construction industry, the term productivity and its definition can vary with its application to different areas of the construction industry ranging from industry-wide economic perceptions to individual-measurement perspectives (Thomas et al., 1990). There are various terms referring to productivity in construction such as production rate, unit rate, performance factor, cost factor, and efficiency. Within the construction industry, productivity commonly refers to labor productivity. Among the numerous terms of productivity, the most common measure of labor productivity, called the *unit rate*, is defined as the work-hours used during a specific time frame divided by the quality of work performed during the same time frame (Thomas and Mathews, 1986), as shown in Equation 2.1. The most common time frames are daily, weekly, monthly or the entire construction project duration (Thomas and Raynar, 1994). From the mathematical expression below, it is apparent that greater productivity means less work-hours expended per unit of work. Labor productivity can be increased either by increasing the output under the same amount of input or decreasing input while the same amount of output is achieved.

$$\textit{Productivity (Unit Rate)} = \frac{\textit{Input}}{\textit{Output}} = \frac{\textit{Work-hours}}{\textit{Quantity of work installed}} \qquad \text{(Equation 2.1)}$$

To avoid confusion, this research study establishes the unit rate as the definition of productivity. *Masonry productivity* is defined, therefore, as a measure of input (work-hours) per unit of output (area of masonry work) as shown in Equation

2.2, i.e. work-hours per square foot (WH/SF); that is, the number of work-hours required to install a square foot of masonry-face area.

$$\textit{Masonry Productivity} = \frac{\textit{Work-hours}}{\textit{Unit of masonry work area}} \qquad \text{(Equation 2.2)}$$

2.1.2 Variability of Productivity

It is universally accepted that the actual labor productivity varies throughout the duration of an activity. To measure construction productivity, several different approaches can be made depending upon the time frame presented in the productivity data, i.e., whether productivity is reported daily, over some other period of time, or cumulatively to date (Thomas and Kramer, 1988). *Daily productivity* is simply defined as daily work-hours divided by daily quantities of work installed. Similar to daily productivity, period productivity is determined by work-hours during the period divided by quantities of work installed during the period. A moving-average approach is an alternative approach to daily and period calculations. Moving-average productivity is calculated for a set period of time. As the data for another day are collected, they are added to the existing data and then the data from the oldest day are removed. In another approach, cumulative productivity is the total work-hours divided by the total quantities installed to date. Figures 2.1 and 2.2 illustrate the difference among daily productivity, 5-day moving-average productivity, and cumulative productivity.

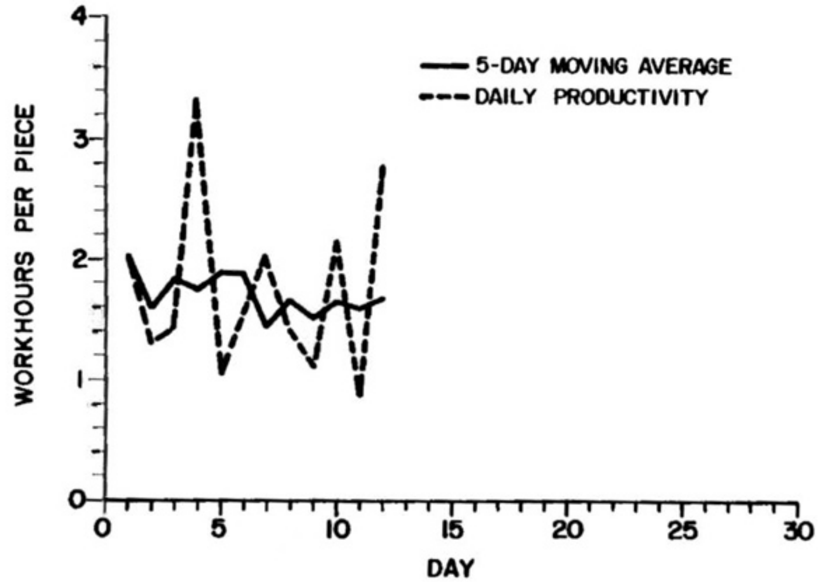


Figure 2.1 Daily and Moving-Average Productivity for the First 12 Days of Structural Steel Erection (Thomas and Kramer, 1988)

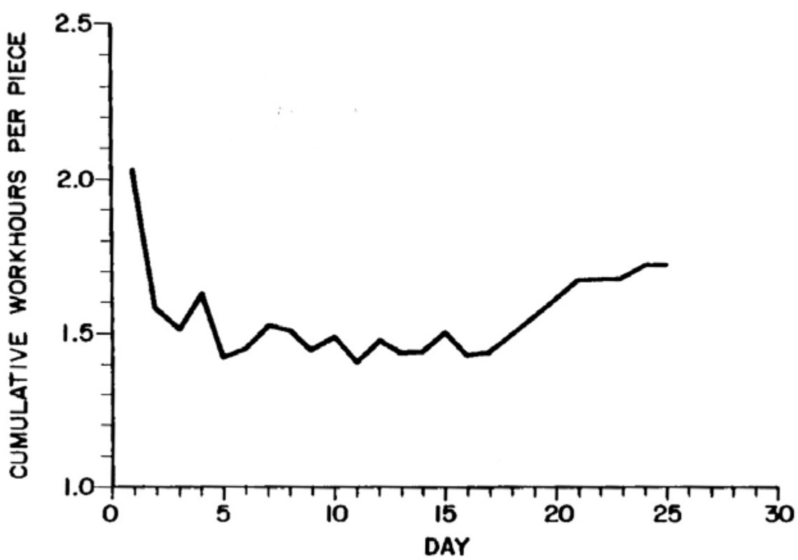


Figure 2.2 Cumulative Productivity for Structural Steel Erection (Thomas and Kramer, 1988)

Different approaches of measured productivity offer different advantages and disadvantages. The plot of daily productivity can show significant fluctuation because actual productivity is usually affected by various productivity factors during the construction process; the plot therefore provides immediate feedback to draw attention to problems that occurred. On the other hand, the plot of productivity over the whole period of an activity neglects daily variations and lack of timeliness in receiving feedback. The single-fixed value of productivity for an activity, however, is typically used to estimate an activity duration because it is simple, convenient, and easy to use. Cumulative productivity is generally adopted by contractors to price an activity (Thomas et al., 1990), to evaluate the work progress in general, and to forecast the final productivity rate upon the completion of the activity (Thomas and Kramer, 1988). The advantages, disadvantages, and uses of each approach are presented in Table 2.1.

Table 2.1 Advantages, Disadvantages, and Uses of the Forms of Productivity Calculations (Thomas and Kramer, 1988)

Approach	Advantages	Disadvantages	Uses
Daily	• Immediate feedback • Provides a sense of magnitude of a particular problem • Supports the identification of causes	• Wide variations possible which are difficult to explain • Calculations done daily	• Draws attention to problems that occurred that day • Facilitates the development of strategies to prevent reoccurrence
Period	• Fewer Calculations • Summaries needed only periodically • Fluctuations in the data not as great as with daily calculations	• Lack of timeliness of feedback • Daily variation hidden • Limited number of data points on which to base conclusions regarding trends • Fails to support the identification of causes	• Summaries for upper-level managers • Can be useful in establishing short-term goals
Moving Average	• Daily feedback • Information not grossly distorted by one unusually good or bad day	• Calculations more tedious	• Analysis of short-term trends
Cumulative	• More closely relates to cost and profitability since total values are used	• As work-hours and quantity increase, the slope changes very slowly and by small increments	• Forecasting probable outcome • Critiquing overall progress

2.1.3 Productivity and Estimate

Productivity is commonly used to estimate an activity duration and labor cost required for a certain activity. Productivity is ascertained from the internal productivity data gathered from past projects or the subjective estimate of experienced personnel. Labor productivity is also available in several cost manuals related to the construction industry. One of the available sources is *Means Building Construction Cost Data* (Means), which is generally used in building construction cost estimating. Means provides crew-based productivity based on the fact that most construction activities are completed by crews involving more than one type of labor, instead of by individual labor trade. Table 2.2 shows a list of common types of labor trade in masonry building construction.

Table 2.2 Common Types of Labor Trade in Masonry Building Construction (Means, 1999)

Abbreviation	**Trade**
Bric	Bricklayers
Brhe	Bricklayer Helpers
Carp	Carpenters
Eqlt	Equipment Operators, Light Equipment
Eqol	Equipment Operators, Oilers
Tilf	Tile Layers, Floor
Tilh	Tile Layer Helpers

To determine an activity duration, Means portrays productivity by the number of labor-hours. *Labor-hour figure*, also called *labor-hour unit* or *productivity rate*, is defined as the number of labor-hours required for a given crew to install one unit of work, i.e. labor-hours per square foot of the work installed. The duration of an activity is determined by multiplying the quantity of work by the labor-hour figure. The quantity of work for an activity is acquired from the scope of work specified in project contract documents. Table 2.3 shows common crew compositions and labor-hour figure for different work items in masonry building construction.

Table 2.3 Crew Compositions and Productivity (Means, 1999)

Work Item	Crew	Unit	Labor-Hour
Brick Veneer Standard, select common 4" x 2-2/3" x 8" (6.75/S.F.)	D-8: 3 Bricklayers 2 Bricklayer helpers	M	26.667
Concrete Block, Back-Up Sand aggregate 8" x 16" x 12"	D-9: 3 Bricklayers 3 Bricklayer helpers	S.F.	0.132
Granite Veneer, published face, gray 3/4" to 1-1/2" thick	D-10: 1 Bricklayer foreman 1 Bricklayer 2 Bricklayer helpers 1 Equipment operator (crane) 1 Truck crane, 12.5 Ton	S.F.	0.308

Productivity data provided in Means is developed over an extended period reflecting national average values without accounting for factors present during the construction execution. The failure to consider variability of productivity can negatively influence the accuracy of the estimate of an activity duration and the labor cost for construction planning and scheduling. In practice, extreme caution should be exercised in any estimate to determine various factors that might occur during the project execution.

2.1.4 Loss of Productivity

One of the major issues facing the construction industry is loss of productivity. As shown in Figure 2.3, *loss of productivity* is defined as the difference between the total work-hours reasonably expected for the anticipated normal conditions and the total work-hours actually measured from the construction site. With respect to the definition of productivity, as shown in Equation 2.3, loss of productivity is also described as the lost work-hours per unit of area of the work installed. As shown in Equation 2.5, the percentage of productivity loss (%PL) is defined as the loss of productivity divided by estimated productivity, and then multiplied by 100. For masonry operations, *loss of masonry productivity* and *percentage of masonry productivity* are defined according to the previous general definitions (Equations 2.4 and 2.6).

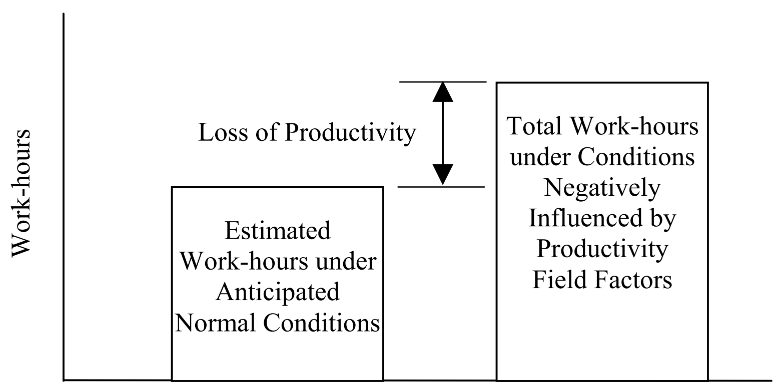


Figure 2.3 Definition of Productivity Loss

$$\textit{Loss of Productivity} = \frac{\textit{Lost work-hours}}{\textit{Unit of work area}} \quad \text{(Equation 2.3)}$$

$$\textit{Loss of Masonry Productivity} = \frac{\textit{Lost masonry work-hours}}{\textit{Unit of masonry work area}} \quad \text{(Equation 2.4)}$$

$$\textit{Percentage of Productivity Loss} = \frac{\textit{Loss of productivity}}{\textit{Estimated productivity}} \textit{ x 100} \quad \text{(Equation 2.5)}$$

$$\textit{Percentage of Productivity Loss} = \frac{\textit{Loss of masonry productivity}}{\textit{Estimated masonry productivity}} \textit{ x 100} \quad \text{(Equation 2.6)}$$

Loss of productivity is usually caused and observed when there are unanticipated conditions. However, unanticipated conditions do not always result in productivity loss (Halligan et al., 1994). Moreover, a particular condition that initiated productivity loss on one project will not result in the same loss on another project (Halligan et al., 1994). Also, the existence of a labor cost overrun is also not acceptable evidence of productivity loss (Schwartzkopf, 1995). For example, there could be an inaccurate estimate or extra work was required to perform the activity.

A significant number of research and industry efforts have been made to measure productivity loss due to negative productivity factors. Many factors affect construction productivity through complex interactions among them. Most of the literature has failed to reveal how various effects interact. Furthermore, most studies concentrate on the effect of a single factor while neglecting the effects of other factors that may exist during the measurement period (Borcherding and Alarcon, 1991). More importantly, the results of these studies have generally been based on limited data, judgment and experience of construction personnel, and the literature usually provides very little insight on database characteristics and data collection procedures (Borcherding and Alarcon, 1991). Factors that are currently of interest among researchers and practitioners include change orders, overtime, adverse weather, congestion, and the learning curve. The key to success in determining productivity loss lies in intensive studies considering several factors encountered during the construction execution, and also, studies which can then be applied to various individual projects.

2.1.5 Loss of Productivity and Project Cost

In the construction industry, it is inevitable that loss of productivity can impact project cost to contractors and subcontractors. The cost of labor for a construction project can exceed 40 or 50% of the total construction cost (Heather and Summers, 1996), and some productivity factors can cause up to 35% or more of productivity loss in severe working conditions such as adverse weather and environmental conditions (MCA, 1976; Leonard, 1987; NECA, 1989; Hester et al., 1991).

Many relevant cost items have been encountered when considering cost of labor due to productivity loss. In addition to the direct cost of additional work-hours due to productivity factors, there are several other costs associated with the additional work-hours that are often overlooked, including wage escalation and labor burdens. Wage escalation refers to a situation when delays, changes, or other actions of the owner are present and a contractor or subcontractor is required to pay its workers at a rate higher than anticipated, which push performance of the contract into a higher wage period (The Army of Corps of Engineers, 1979; Schwartzkopf, 1995). Labor burdens are costs that are directly related to the employment of workers but are not reflected in the employee's wages. Common labor burdens are state and local taxes, state and federal unemployment taxes, workers' compensation and other insurance, benefits, and supervisory costs (Schwartzkopf, 1995).

Other important relevant cost items are materials, equipment, and tools costs. The effect of productivity factors on construction materials can take several forms. The most common one involves partially completed construction such as the cost of materials waste and loss, the cost of additional temporary protection, and the cost of re-handling materials (Dieterle and DeStephanis, 1992). Furthermore, if vendors need to defer material shipments beyond the originally scheduled date, a cost of materials shipments or a cost of additional storage time may be applied (The Army of Corps of Engineers, 1979). Costs of equipment and tools are significant cost items on many construction projects, especially ones involving heavy civil work. If additional labor is required, additional equipment and tools are generally required due to the simple fact that most of the work is not done by bare hands alone (Schwartzkopf, 1995). General impacts of productivity factors associated with changes of equipment are equipment standby costs and increased iterations of mobilization and demobilization.

2.1.6 Productivity Trends

Prior to the mid 1960s, the construction industry reflected a growth in productivity (Stall, 1983). Since then, poorer productivity has been one of the most frequently discussed topics in the construction industry. In 1968, the Construction Roundtable was established due to the concern over the increased cost of construction resulting from an increase in the inflation rate and a significant decline in construction productivity (Thomas and Kramer, 1988). Also, in 1965 the United Nations Committee on Housing, Building, and Planning (UNC) published a significant manual concerning the effect of repetition on building operations and processes (UNC, 1965). The study revealed that the need for an increase in productivity was probably more urgent in the building industry than in many other industries. It was necessary to adopt, as far as possible, industry-wide principles of production throughout the building process. However, it was recognized that careful adaptation would be necessary to apply the knowledge and experience gained in the manufacturing industry to the building construction industry (Borcherding and Alarcon, 1991).

It was not until the early 1970s that construction productivity began to slightly increase (Howenstine, 1975). During 1981 and 1986, Koehn and Manuel (1988) performed a survey regarding variation in work improvement potential for small and medium contractors. The findings of this study show that there was a significant reduction in the number of firms who identified productivity as a substantial problem in the construction industry, revealing a decrease from 52% to 34% since 1981. This can have a twofold implication: either there was an improvement in productivity for small and medium contractors during the five-year period under consideration, or a larger number of more productive contractors than nonproductive contractors responded to the second research study. Nevertheless, an increase in productivity in the 1980s and 1990s has recently been confirmed by a research study based on data from Means and 72 projects in Austin, Texas (Allmon et al., 2000; Paul, 2001).

An increase in productivity in the construction industry can be successfully achieved by several means. First, a number of recent research studies have shown that productivity improvement is fundamentally based on management practices (Chutler, 1984; Koehn and Caplan, 1987; Koehn and Manuel, 1988; Thomas et al., 1986). Thus, areas recognized as having high potential for productivity improvement include supervision, labor relations, planning, scheduling, communication, work environment, and the ability to recognize and reward exemplary efforts (Chutler, 1984; Revay, 1984; Koehn and Caplan, 1987). Second, the positive variation of construction productivity may be the consequence of productivity improvement programs initiated by construction firms or possibly the response to the slump in the construction industry that limited the employment opportunities for poorly qualified trades (Koehn and Manuel, 1988). In addition, the productivity improvement is a result of an advancement of technology (Allmon et al., 2000; Paul, 2001).

2.2 Productivity and Project Performance

In a construction project, project performance is of prime interest to all project participants. It is important to understand how project performance was assessed, and how to interpret the assessment. Several definitions of project performance have recently been published. Oglesby et al. (1989) state that productivity associated with project cost is generally a measurement tool for performance satisfaction. Better productivity means better project performance, referring to finishing the work at a fair price for the owner and at a reasonable profit for the contractor. Thomas and Kramer (1988) refer to *project performance* as a measure of construction efficiency, which is defined as the planned productivity divided by the actual productivity. This ratio is sometimes called a performance factor or a rate ratio; a ratio greater than 1.0 implies better-than-planned performance if estimated productivity is divided by achieved productivity. The Bureau of Engineering Research (1986b) refers to project performance as a measurable characteristic including cost, schedule, quality, safety, and participant satisfaction. However, the latter characteristic is closely related to the others, meaning that better performance of cost, schedule, quality, and safety generally results in greater satisfaction of project participants. Figure 2.4 therefore shows that project performance and its major components are closely associated with productivity. The following sections will discuss productivity and project cost, schedule, quality and safety.

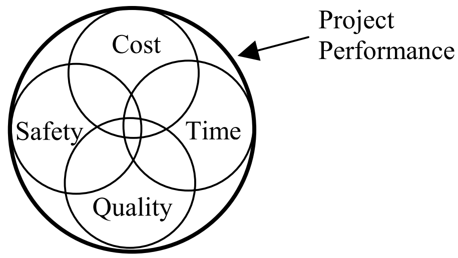


Figure 2.4 Project Performance and its Components

2.2.1 Productivity and Project Cost

A relevant literature review indicates that productivity is one of the major factors affecting the project cost (Thomas and Mathews, 1986; Thomas and Kramer 1988). Based on its definition, productivity principally involves the input (work-hours) and the output (quantity of work), and the work-hours directly influence labor cost, which is one of the major project costs in building construction projects. Therefore, it is conceivable that productivity has a significant direct impact on the project cost. In other words, productivity can be interpreted as a project cost for the owner and to a profit for the contractor (Thomas and Kramer, 1988).

2.2.2 Productivity and Project Schedule

In the construction industry, time involves two essential elements. The first element involves the time required to complete the project, or on-time project completion. Equally important, the second element refers to scheduling of the tasks and activities during the construction process. A number of recent research studies have focused on time and productivity in the construction industry (Hendrickson et al., 1987; Thomas, 1992; Thomas and Kramer, 1988; Thomas and Mathews, 1986). Many studies show that productivity and time are closely related. The primary reason for this is that productivity data are generally used to determine an activity duration for scheduling; hence, accurate productivity tends to result in a more precise schedule. Furthermore, a decline in productivity can contribute to schedule delays (Borcherding and Garner, 1981). However, satisfactory productivity performance and schedule performance are not always present concurrently (Thomas and Kramer, 1988). Target productivity can be achieved even through the work may be behind schedule. Conversely, the schedule can be met even with loss of productivity. To have a comprehensive description of project performance, it is necessary to simultaneously look at both productivity and schedule performances (Thomas and Kramer, 1988). One of the basic methods of schedule assessment is to compare planned and actual schedules, which can be presented by a schedule performance index for a control account (Thomas and Kramer, 1988). The *schedule performance index* is defined as earned work-hours to date divided by scheduled work-hours to date, as shown in Equation 2.7. A value of schedule performance index greater than 1.0 refers to better schedule performance, or work ahead of schedule.

$$\textit{Schedule Performance Index} = \frac{\textit{Earned work-hours to date}}{\textit{Scheduled work-hours to date}} \qquad \text{(Equation 2.7)}$$

2.2.3 Productivity and Project Quality

Many construction experts are of the opinion that quality is one of the key project performances attributes. Quality usually includes two significant components: the meeting of specified requirements and the satisfaction of the owner's needs (Oglesby et al., 1989). The construction industry has recently recognized the importance of quality and its associated cost (Burati and Farrington, 1987). At the job level, it is important to complete all job details with specified quality, as stated in the project contract. If the quality of the work is poor, and the contractor needs to perform some rework, the associated cost and time can be a major concern among the project participants (Burati and Farrington, 1987). This can also raise productivity problems regarding morale and willingness of the workers to perform the work effectively.

2.2.4 Productivity and Project Safety

Safety has recently been one of the major concerns in the construction industry. According to the Bureau of Labor Statistics (2000), the U.S. construction industry has reported the largest number of job-related fatalities of any industry. During the 1992 to 1999 study period, about 1,100 workers were killed each year in the construction industry. The fatal-injury rate facing the industry's 8.5 million workers is approximately three times greater than the rate for the average worker in all other industries. It is conceivable that the nature of construction is partly to blame for a significant number of serious accidents. Construction projects are often large and involve heavy materials and equipment (Liska, 1993; Oglesby et al., 1989). Equally important, workers usually work at heights, in excavations, underground, or in other high-hazard locations (Liska, 1993; Oglesby et al., 1989). Furthermore, work activities and crew membership change frequently (Oglesby et al., 1989).

A review of the relevant literature has shown that due to these characteristics, accidents in construction have contributed to an increase in the project cost and to a decrease in productivity. Findings from relevant investigations state that accidents have increased the project costs, both direct and indirect (Handa and Rivers, 1983; Hinze, 1991; Liska, 1993). The direct costs include costs of injuries and deaths, worker's compensation and insurance premiums. The indirect costs consist of lost workdays, time lost from other crews and management, equipment and material damage, worker morale, and ultimately company reputation. It is clearly apparent that the time lost from crews and management, and the damage to equipment and materials directly impact productivity. In such cases, accidents normally distract the attention of management from its primary function, to get the job done, and crews wait for new equipment and material, resulting in loss of productivity. Simply stated, safety is a serious concern for the government and in the courts, and safety violations and injuries can be costly as well as contributing to human suffering, negative publicity, and lost productivity (Bureau of Engineering Research, 1991). The impact from incidents can be eliminated though better on-site management by improving management functions such as planning, scheduling, follow-up, equipment maintenance, and problem documentation (Handa and Rivers, 1983).

2.2.5 Summary of Productivity and Project Performance

Labor productivity is considered to have a major impact on project performance, which is composed of cost, time, quality, and safety. During the construction execution, however, multiple factors influence labor productivity and result in an impact to project performance. Factors that result in loss of productivity therefore have significant impacts on project performance. This mechanism is simply illustrated as shown in Figure 2.5.

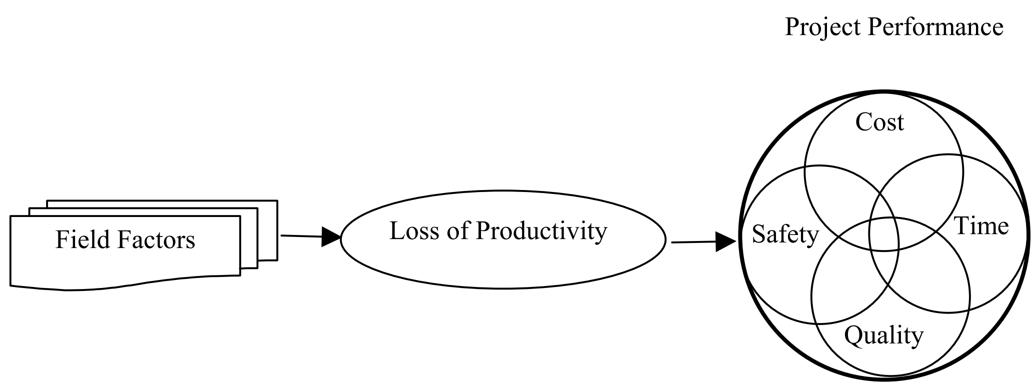


Figure 2.5 Impact of Loss of Productivity on Project Performance

2.3 Productivity Factors

Productivity factors have recently become one of the most frequently discussed topics in the construction industry. These factors affect construction productivity through complex interaction resulting in loss of productivity. A decrease in productivity takes many forms, and is therefore difficult to quantify before the fact (The Army of Corps of Engineers, 1979). Quantitative evaluations of the effects of these factors are needed for many purposes including construction estimating, planning, scheduling, and proof of damages in construction claims. Numerous research studies have been conducted to determine or measure the effects of specific factors in terms of productivity loss. However, there has not been significant research for measuring how the various effects interact (Borcherding and Alarcon, 1991; Schwartzkopf, 1995).

Furthermore, the past studies vary dramatically depending on a variety of sources of data, methodologies, types of projects, and other characteristics (Borcherding and Alarcon, 1991). Therefore, these past studies are best used to validate or invalidate actual performance in the field rather than act as the sole indicator of productivity loss. Due to the complex interaction of different factors that influence labor productivity, the prediction of lost productivity can best be estimated as a range of losses that can be anticipated rather than a single lost productivity value (Schwartzkopf, 1995). This complexity highlights the need for the standardization of collection procedures of productivity information, and the collection of large amounts of comparable information (Borcherding and Alarcon, 1991). This effort is being carried out by researchers and institutions linked to the construction industry (Borcherding and Alarcon, 1991).

Several productivity factors have been quantified in the past decades. Due to the complex relationships among these factors, some factors have a direct effect on productivity, while others are intermediate factors (Borcherding and Alarcon, 1991). Some factors are within the control of contractors, while others are not. Most research studies presented herein have focused on factors related to a construction project itself rather than the industry's or trades' work ethic and global issues such as the economy, union policies, or governmental regulations. Borcherding and Alarcon (1991) classify these factors into seven categories listed as follows. Using these categories, they reviewed and listed numerous studies quantifying productivity loss due to productivity factors.

1) Schedule acceleration
2) Changes
3) Resources and site management
4) Management characteristics
5) Project characteristics
6) Labor and morale
7) External conditions

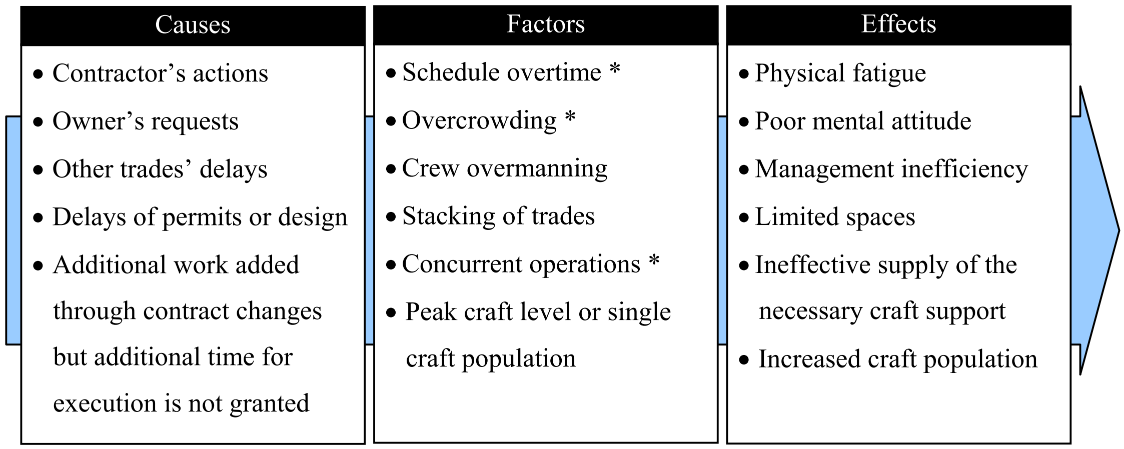
The following sections of this chapter will present each category of the above productivity factors. Each section will discuss the associated factors within each category, the common causes and effects of each factor, and management practices needed to minimize the impact of these factors within each category. The causes and effects of productivity factors in a category are illustrated in the cause-effect diagram as shown in Figure 2.6. There are three elements in this cause-effect diagram: causes, factors, and effects. Productivity factors result from several causes; meanwhile the factors also result in several further effects. In fact, causes and effects of productivity factors can also be considered as productivity factors affecting labor productivity. The final effects will result in loss of productivity.

Figure 2.6 Cause-Effect Diagram of Productivity Factors

This dissertation mainly focuses on major field factors or field disruptions negatively affecting productivity. The term *field disruption* can be defined as an anticipated condition or event that adversely affects labor productivity. These field factors will be identified in the following sections of this chapter and will be discussed in detail in later chapters.

2.3.1 Productivity Factors Associated with Schedule Acceleration

The influence of schedule acceleration is of prime interest to researchers and project participants in the construction industry. Schedule acceleration, sometimes referred to as buying back time, occurs when the contractor is required to perform the work on a shorter schedule than what is included in the contract or to accomplish a greater amount of work within the original schedule (Borcherding and Alarcon, 1991). Expediting occurs when the contractor is required to complete the work before the original completion date included in the contract. Numerous causes of schedule acceleration recognized in the construction industry include contractor's actions, owner's requests, other trades' delays, delays of permits or design, and additional work added through contract changes while additional time for execution is not granted (Schwartzkopf, 1995). In the construction industry, schedule acceleration can be accomplished though several methods including scheduled overtime, stacking of trades, crew overmanning, working in shifts, changed work methods, and altered schedules or work sequence. As a result of these methods, schedule acceleration can cause loss of productivity when the organizational infrastructure cannot supply the necessary craft support including materials, tools, equipment, and inspections, which results in waiting times (Borcheding and Alarcon, 1991). Furthermore, schedule acceleration may create problems related to increased craft population such as physical interference, overcrowding, competition for equipment, facility and space, and lack of skilled labor (Borcheding and Alarcon, 1991). Productivity factors associated with schedule acceleration encompass overcrowding, overmanning, peak craft level, single craft population, and overtime. Figure 2.7 presents the cause-effect diagram of factors associated with schedule acceleration. Asterisk marks, shown in this figure and other cause-effect diagrams of factors which will be presented later in this chapter, represent the field factors on which this study will focus. These factors are field disruptions that are beyond the direct control of masonry contractors.



** Field factors on which this study will focus*

Figure 2.7 Cause-Effect Diagram of Factors Associated with Schedule Acceleration

Loss of productivity due to schedule acceleration can be minimized by effective management practices. Schedule acceleration usually requires accelerated support services due to a decrease in procurement and engineering lead time. Adequate engineering and procurement supports therefore should be available. Furthermore, schedule acceleration normally causes numerous inquiries from the field that requires rapid responses, so sufficient attention and engineering information should be provided (Schwartzkopf, 1995). It might also be necessary to consider alternatives to accelerated support services, for instance overtime, working shifts, changed schedules, alternative construction methods, or hiring a large number of less productive workers.

2.3.2 Productivity Factors Associated with Changes

In recent years, there have been numerous investigations involving construction changes. A change is a modification in the original scope of work, contract schedule, or cost of work, while a change order is a formal contract modification encompassing a change into the contract (Hester et al., 1991). It is likely that changes will occur during any construction project, which in turn can significantly influence construction productivity. Causes of changes include defective plans and specifications, incomplete design, differing site conditions, schedule delays, substitutions, and scope changes (Schwartzkopf, 1995). CII (2000) states that the most common causes of change orders are additions, design changes, and design errors and omissions. One of the major reasons for productivity loss due to changes is that changes generally interrupt a sequence of ongoing activities. Changes, in most cases, also generate loss of momentum, loss of efficiency, reassignment of manpower to other tasks, demotivation, delays, learning curve effects, and ripple effects on other activities, resulting in loss of productivity (Leonard, 1987; Borcherding and Alarcon, 1991). Loss of momentum refers to the loss of productivity that exists when individual workers or crews are interrupted for a change or any other reason and the workers then become less productive. Furthermore, other major change-related causes of productivity loss include inadequate coordination or scheduling, acceleration, and changes in sequence or complexity (Leonard, 1987). New changes also can occur due to errors in previous changes made under pressure. These productivity factors generally have accounted for significant loss of productivity. Figure 2.8 shows a list of productivity factors and common causes and effects of these factors.

Causes	Factors	Effects
• Defective plans and specifications	• Change orders	• Loss of momentum
• Incomplete design	• Learning curve *	• Loss of efficiency
• Differing site conditions	• Engineering errors and omissions *	• Reassignment of manpower
• Schedule delays	• Ripple or ripple effect *	• Demotivation
• Substitutions	• Delays	• Schedule delays
• Scope changes	• Reassignment of manpower or sequencing *	• Learning curve effects
• Inadequate coordination or scheduling		• Ripple effects
• Acceleration, and changes in sequence or complexity		• Other changes

** Field factors on which this study will focus*

Figure 2.8 Cause-Effect Diagram of Factors Associated with Changes

Some management practices can be implemented to minimize the impacts of changes. Management techniques that encourage early resolution tend to decrease the costs of changes and claims (Halligan, 1987). Proper management of changes requires information on the expected conditions to be delivered to field personnel in a timely and justifiable manner (Halligan, 1987). As a result, changes generally require additional administrative and engineering efforts (Borcherding and Alarcon, 1991). An understanding of the causes of changes is required in order to establish effective strategies for managing changes (Thomas and Napolitan, 1994). Consequently, adequate and effective administrative and engineering support should be available at the outset to ensure proper planning, organization, management, control, and assessment. When changes are made, it is important to issue changes as early as possible (CII, 2000), to provide sufficiently detailed drawings and documents related to the changes, and to assign separate crews to perform the changed work (Schwartzkopf, 1995).

2.3.3 Productivity Factors Associated with Resources and Site Management

A number of recent research studies present productivity factors related to resources and site management. Inadequate resources and poor site management can significantly impact productivity simply because construction crews need the resources necessary to performing work in an efficient environment. The necessary resources include materials, tools, equipment, design drawings, inspections, and knowledge of the work. Findings from several research investigations reveal numerous productivity factors including poor site conditions, logistics, unbalanced crews, site access, and poor lighting and housekeeping. Loss of productivity generally occurs when craftsmen wait for resources, frequently travel to obtain materials, and work slowly or ineffectively due to defective tools or equipment (Borcherding and Alarcon, 1991). Common causes of these factors include defective tools and equipment, delays in material delivery, poor material handling, ineffective site layout, poor site maintenance, poor construction methods, and unbalanced crews. Figure 2.9 shows several productivity factors associated with resources and site management, as well as common causes and effects of these factors.

Causes	Factors	Effects
• Defective tools and equipment • Delays in materials delivery • Poor materials handling • Ineffective site layout • Poor site maintenance • Poor construction methods • Unbalance crews • Dust or hazardous conditions • Lack of management support	• Site conditions and organization • Methods and equipment • Materials and tools availability or logistic * • Materials handling space • Unbalanced crew or crew size * • Site and dispersion of work tasks • Interference • Site access * • Lighting and housekeeping	• Craftsmen wait for resources • Frequently travel to obtain materials • Labor morale • Increase in traveling and idle time • Disrupted material flow or procurement • Alter labor rhythm • Break up of the original team effort • Limited spaces • Impairment

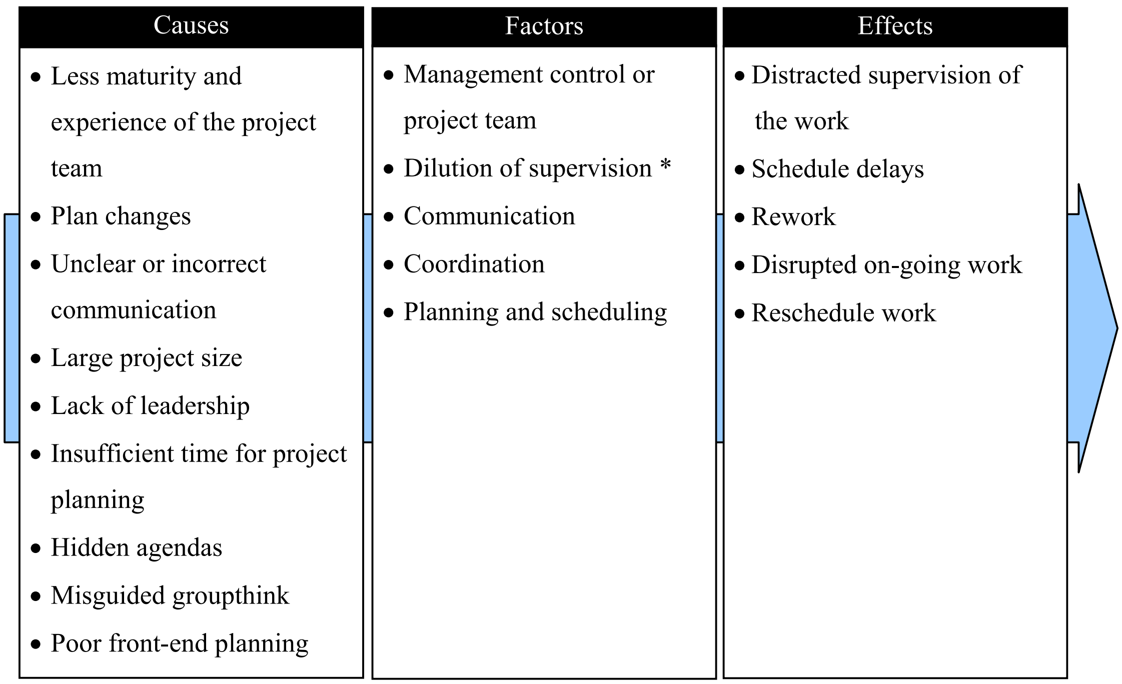
** Field factors on which this study will focus*

Figure 2.9 Cause-Effect Diagram of Factors Associated with Resources and Site Management

Good resources and effective site management provide solutions to productivity improvement. Craftsmen can perform the work productively only when the necessary resources for that work are available in the proper place at the right time (Schwartzkopf, 1995). Effective procurement and site delivery, engineering and design lead time, communication between designers, contractors, and subcontractors are required to minimize loss of productivity in construction. Management techniques particularly relevant to unforeseen site conditions should be implemented to minimize loss of productivity. Solid management techniques including the use of interpretive reports, early resolutions of claims, proper scheduling, suitable cost accounting, and a good relationship between the owner and the contractor are significant to the successful management of unexpected site conditions (Halligan, 1987). Recent research studies of Construction Industry Institute (CII) have revealed that formal materials management programs have the potential to yield significant construction cost savings. However, some small and medium-sized commercial contractors may not consider an integrated materials management program to be cost effective (Thomas et al., 1989).

2.3.4 Productivity Factors Associated with Management Characteristics

Several research studies have focused principally on management characteristics. Management includes project participants who are not directly performing field labor, i.e. contractor and subcontractor management personnel, project design and engineering teams, materials and equipment procurement personnel, inspectors, and owner representatives. Project management has a significant impact on construction productivity due to the fact that management participants not only provide all necessary resources for the work, but also perform planning, scheduling and control for all construction processes. How management performs their jobs, therefore, can potentially cause productivity loss. Figure 2.10 presents common causes and effects of productivity factors related to management characteristics.



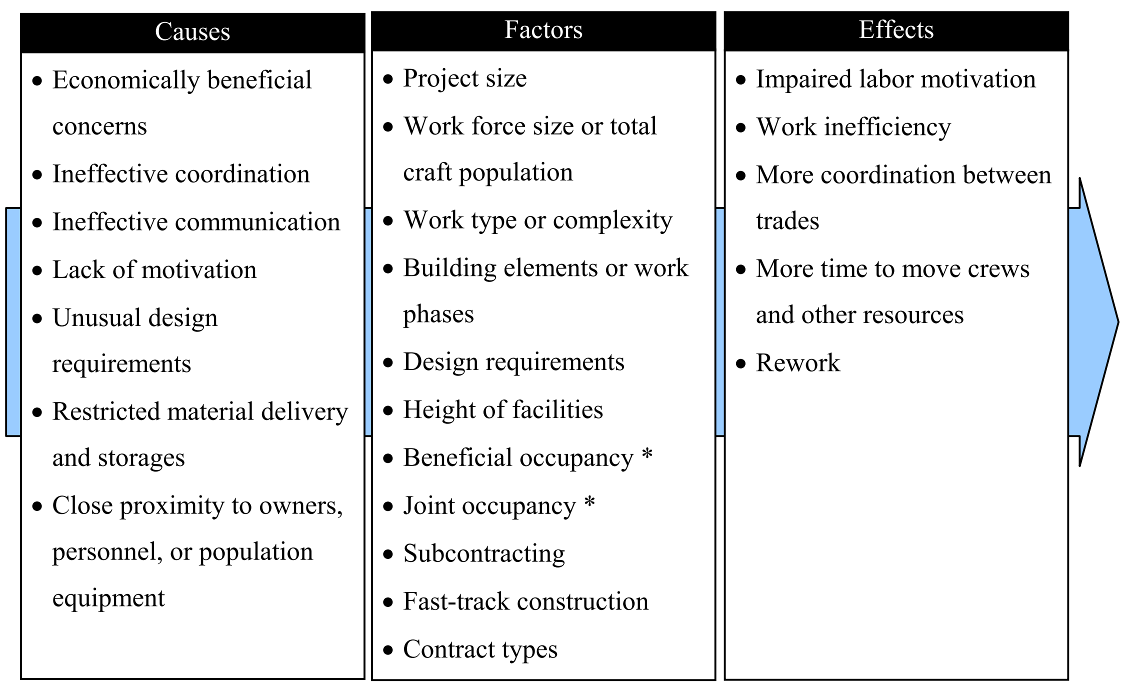
** Field factors on which this study will focus*

Figure 2.10 Cause-Effect Diagram of Factors Associated with Management Characteristics

Several recommendations have been made to minimize impacts of management characteristics on labor productivity. Effective planning, scheduling, and control should be implemented. This requires successful management techniques (Halligan, 1987), effective communication tools (Thomas et al. 1998), and knowledgeable onsite engineers (Schwartzkopf, 1995). Design and engineering lead time and additional engineering and procurement supports should be considered because they have major impacts on materials availability, rework, overcrowding, crew interfering, and inspection. Pre-project planning should also be implemented because the project scope changes tend to decrease with an increasing level of pre-project planning (Gibson and Hamilton, 1994; Cho, 2000). According to numerous research studies conducted at CII, pre-project planning and constructability during conceptual planning have a significant impact on the outcome of a construction project (Bureau of Engineering Research, 1986a; Gibson et al., 1993; Griffith and Gibson, 1997; Tatum et al., 1986; Bureau of Engineering Research, 1986), so these aspects should be effectively implemented.

2.3.5 Productivity Factors Associated with Project Characteristics

In recent years, researchers and construction practitioners have accounted for the importance of project characteristics on construction productivity. Project characteristics that affect labor productivity include both physical and non-physical characteristics of projects (Schwartzkopf, 1995). Project physical characteristics include building height, project size, and project location, while non-physical characteristics include the degree to which engineering overlaps construction, the turnover within the project management workforce, the management of a project by a strong project management team, and the ownership of a project, i.e. private or public owners (Schwartzkopf, 1995). These project characteristics generally involve several problems that impair labor motivation and efficiency resulting in a loss of productivity. Causes of the problems can be the inability of management to efficiently coordinate the work among a large number of crews, ineffective communication in deep hierarchical organizations, and lack of motivation (Borcherding and Alarcon, 1991). Productivity factors associated with project characteristics include project size, work type, work force size, beneficial occupancy, joint occupancy, and contract types. Figure 2.11 provides a list of these factors and their general causes and effects.



** Field factors on which this study will focus*

Figure 2.11 Cause-Effect Diagram of Factors Associated with Project Characteristics

To minimize the impacts of factors associated with project characteristics, effective construction management techniques should be carefully implemented. The design and planning phases are particularly important due to the fact that many productivity factors such as project size, work type, multistory building, and contract are variables known to all project participants before the start of a project. Due to these reasons, pre-project planning, constructibility, value engineering, and other construction and engineering concepts should be exercised to minimize loss of productivity and increase cost savings. During the executing phase, effective management practices including planning, scheduling, control, and communications must be emphasized to minimize the impacts from building elements and beneficial and joint occupancies.

2.3.6 Productivity Factors Associated with Labor and Morale

There have been numerous studies concerned with labor and morale in the construction industry. In a construction project, two major components of the labor cost are wage rates of labor and labor productivity. Of these two, labor productivity experiences greater variation (Neil and Knack, 1984). Since workers perform the construction work, they have a direct control on productivity when necessary resources are available in the proper place at the right time, and therefore worker morale can have a significant impact. The list of common demotivators in construction projects is a long one: lack of materials, project confusion, communication breakdown, rework, unavailability of tools and equipment, disrespectful treatment, lack of recognition, little participation in decision making, lack of cooperation among crafts, incomplete engineering, restrictive or burdensome procedures and regulations, poorly trained foremen, and restrictive work practices in labor agreements (Business Roundtable, 1982). Productivity factors associated with labor and morale include quality of craftsmanship, quality assurance and control practices, absenteeism, and craft turnover. Productivity factors classified into other categories, such as project management, project characteristics, changes, and external conditions, can also significantly influence labor effectiveness. Figure 2.12 shows a list of common causes and effects of factors associated with labor and morale.

To minimize the impact of these factors, it is important to acknowledge that construction labor has a direct control over productivity and that the workers can be motivated. Management should apply appropriate management practices to increase motivation and labor productivity. Providing adequate support and assistance to workers and establishing a cooperative atmosphere among all levels and parties involved are recommended (Borcherding and Garner, 1981). Considerable attention should be directed to engineering lead time, planning and scheduling, communication, and work environment. The Business Roundtable (1982) developed a better understanding of what motivates construction workers, and devised specific programs that can be used on construction job sites to enhance efficiency and productivity. Several other sources have discussed motivators and demotivators of workers in construction as well (Borcherding et al., 1980; Borcherding and Garner, 1981).

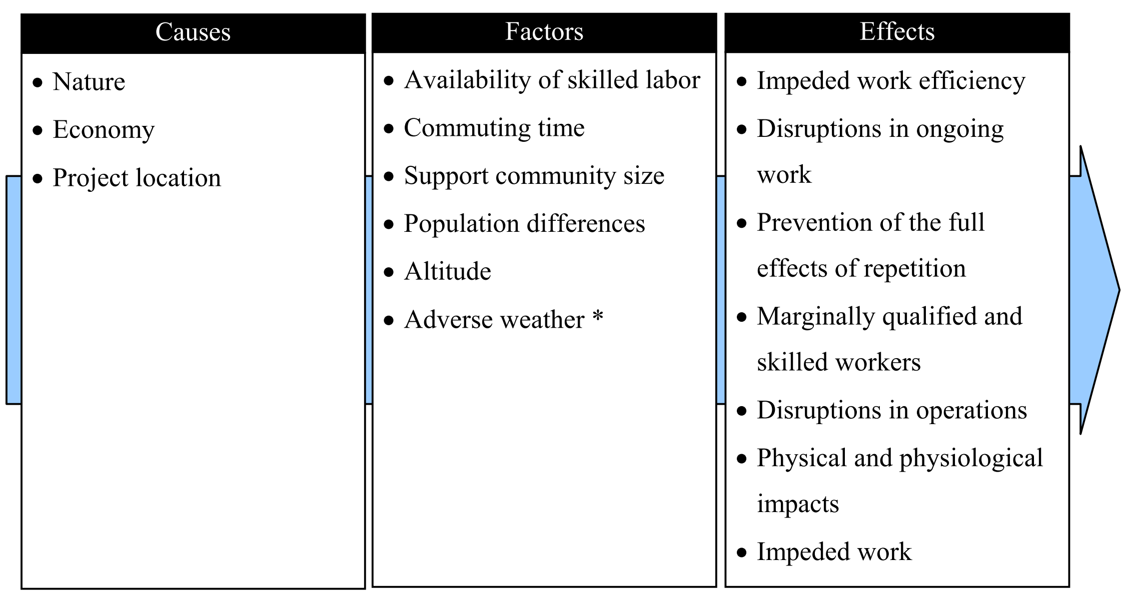
Causes	Factors	Effects
• Poor training • Low payment • Scarce labor • Lack of qualified inspectors • Lack of materials • Project confusion • Communication breakdown • Rework • Unavailability of tools and equipment • Disrespectful treatment • Lack of recognition • Little participation in decision making • Lack of cooperation among crafts • Incomplete engineering • Restrictive or burdensome procedures or regulations • Poorly trained foremen • Restrictive work practices in labor agreements • Factors in other categories	• Quality of craftsmanship • Quality assurance and control practices • Absenteeism • Craft turnover • Wages • Incentives • Fatigue * • Morale and attitude *	• Increased non-productive time • Increased waiting time • Rework • Manpower reassignment • Learning curve effect

** Field factors on which this study will focus*

Figure 2.12 Cause-Effect Diagram of Factors Associated with Labor and Morale

2.3.7 Productivity Factors Associated with External Conditions

In the construction industry, it is conceivable that external conditions have a major influence upon labor productivity due to the fact that most construction projects are subject to governmental and union regulations, involve several project participants, require several resources, and suffer exposure to the environment. The external conditions include availability of skilled labor, commuting time, size of the support community, population differences, altitude, and adverse weather. Generally, these external factors not only impede work efficiency but also cause disruptions in ongoing work, and thus prevent the full effects of repetition from being achieved (UNC, 1965). Figure 2.13 represents general causes and effects of factors related to external conditions.



** Field factors on which this study will focus*

Figure 2.13 Cause-Effect Diagram of Factors Associated with External Conditions

The unfavorable influence of external conditions render problems which can hardly be avoided (UNC, 1965). Some management practices, however, can be implemented to minimize loss of productivity. Effective project planning and scheduling, detailed communications, and suitable construction methods depending on the nature and duration of the construction project can partly decrease the impacts of external conditions. Furthermore, it is necessary that management pay attention to specific problems associated with maintaining continuity of work (UNC, 1965), so the disruptions can be controlled punctually. To minimize disputes and claims, specific clauses regarding external conditions should be included in the contract, so that all personnel involved in the project are in agreement when effects due to factors related to external conditions occur.

2.3.8 Effects of Multiple Productivity factors

A number of publications have addressed the issue of multiple productivity factors with respect to the impacts of the complex interaction among them. "**When there are multiple changes on a project and they act in sequence or concurrently there is a compounding effect- this is the most damaging consequence for a project and the most difficult to understand and manage**. The net effect of the individual changes is much greater than a sum of the individual parts" (Hester et al., 1991). This effect generally results in an increase in time and cost to the project. However, developing quantitative evaluations of the effects is challenging and there are few research studies that have been conducted to quantify the compounding effect of multiple factors.

One of the earliest publications regarding quantitative evaluations for productivity factors is that of Dallavia (1952). He proposed a method showing eight categories of productivity factors, with each containing several factors. Each factor has three ranges of production efficiency: low, average, and high. Efficiency percentages for each category can be averaged to determine an overall efficiency percentage multiplier, and then work-hours and costs can be adjusted accordingly. This method, however, assumes that all eight categories of factors are coequal in effect through its averaging process, and it does not include any consideration of basic population group differences (Neil 1984). Another publication by Edmondson (1974) stated that productivity is a function of fixed factors and relative factors. Fixed factors include area labor climate, overall labor availability, and overall labor skill available. Relative factors include size of project versus area labor availability, project schedule and economic conditions, project complexity, and overtime. Fixed factors have accounted for population group differences, and relative factors have been justified for the situations affecting direct work time available and the rate of work during direct time.

The Mechanical Contractors Association of America (MCA) (1976) has presented adverse effects on labor productivity resulting from causes beyond the direct control of mechanical contractors. The primary purpose of this publication is to assist in preparing original estimates and change orders. The publication presents percentages of productivity loss used to compute lost work-hours, which are added onto labor costs of changes or, in some cases, original contract hours. There are 16 productivity factors and each is composed of minor, moderate, and severe conditions. These factors are provided to serve as a reference only or as a starting point when conducting productivity analysis and predicting productivity losses. The paper suggests that these factors should be tested for individual firms and accordingly modified for different projects and crews. However, the paper has several weaknesses. It does not provide sources of the factors, and the data is understood to be based on judgment and experience of personnel on the mechanical side of construction. Recommendations for quantifying multiple factors are not available, and simply adding up many factors results in an extremely high percentage of productivity loss. Furthermore, guidelines and descriptions for different conditions are not available, requiring a subjective decision to be made for quantification. Lastly, the manual does not address whether the factors are to be applied to the entire project, to proportions of the project, only to changed work, or only to specific areas.

The National Electrical Contractors Association (NECA) (1976) has proposed a job factor checklist to be used for adjusting labor units under several conditions. The checklist provides average percentages of loss for several productivity factors, each consisting of different degrees ranging from the least to greatest effects. The manual states that these factors may vary with individual firms. However, the manual does not provide detailed information on how to apply these factors for estimating change orders. Furthermore, the manual fails to illustrate how these factors interrelate. Documentation about quantification of multiple factors is also lacking, and an additive or cumulative computation of these factors can result in extreme values. Equally important, there is no recommendation of whether these factors can be applied to the entire job, the changed job, or the unchanged job.

The recent research literature on multiple impacts to productivity is presented by Neil (1982, 1984). He presented several adjustment factors for several conditions that affect construction productivity, and guidance for selecting the factors. He also introduced a formula to determine a "productivity multiplier" used as an index of productivity comparable with a base area. To select each adjustment factor, a weighted average approach must be considered based on percentage of work-hours of each condition, rather than choosing a worst-possible condition that exists only occasionally. In determining the summation of adjustment factors, all factors applying to both the whole job and the particular task are added while particularly paying attention the time frame each condition prevails.

Another research studies regarding quantitative evaluations for multiple productivity factors is presented by Thomas and Smith (1990). They provide a mathematical model for predicting productivity losses based on field observation and actual empirical data. Nine factor categories are quantified. The model consists of a dependent variable, expected productivity unit rate for anticipated conditions, and three independent variables: normal productivity without disruptions, relative frequency of the factor, and average impact factor. The model recognizes that some factors may have a serious impact on productivity, even though the frequency may be low. On the other hand, some factors may have a relatively low impact on productivity, but the frequency is high. This method is used to compute the expected inefficiencies and to advise the owners of the likely impacts. This model can also be used for calculating the impact of multiple factors, but only nine factor categories are provided. Furthermore, it is important to note that the model does not consider changes other than rework changes.

One of the current, well-known pieces of literature on this topic is that of CII (2000). This study, principally investigated by Hanna, A. S., focused on quantifying the cumulative impact of change orders on electrical and mechanical efficiency. The results of this study include the development of two models. The first model is used to identify if a construction project has been impacted as a result of cumulative change, whereas the second model is used to predict the probable magnitude of the cumulative impact due to that change. Findings from this study show that "percent change is a major contributor to producing an impacted project" (CII, 2000).

2.3.9 Productivity Factors and Project Performance

Numerous productivity factors negatively impact labor productivity, which ultimately influences project performance. This can be graphically presented in a conceptual model of complex interactions among productivity factors, as shown in Figure 2.14. Several factors have direct impacts on labor productivity, while many factors interact among themselves to influence productivity. During the project execution, several factors can affect labor productivity simultaneously or consecutively resulting in a compounding effect moving toward through the impact boundary, as illustrated by the dashed line. This complex phenomenon can create several effects resulting in loss of productivity, finally results in weakened project performance. Quantitative evaluations of the impact of each factor and the compounding effect at the impact boundary are currently of interest to researchers and construction practitioners.

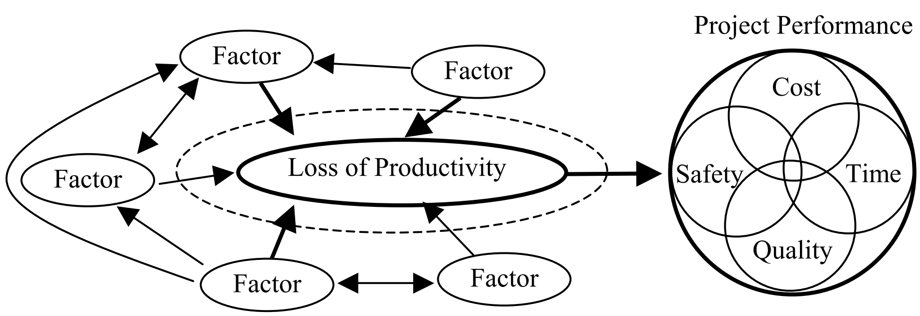


Figure 2.14 Productivity Factors Impacting Project Performance

CHAPTER III

RESEARCH METHODOLOGY

This chapter presents the specific research methodology used by the researcher in the model development and validation process. It covers the issues identification, questionnaire design, data collection and preparation procedures, data analysis techniques, and model development and validation procedures. Various statistical test procedures including descriptive statistics, boxplot study, and analysis of variance (ANOVA) were used throughout the research investigation. Figure 3.1 shows an overview of the various phases of this research investigation process. Each phase contains several steps that are illustrated in detail in the following sections. Figure 3.2 depicts a summary of the model development and validation processes.

The model development process involves research surveys completed by members of Mason Contractors Association of America (MCAA) and Texas Masonry Council (TMC). The model validation process involves another research survey completed by personnel from the Office of Facilities Planning and Construction (OFPC) at the University of Texas at Austin (UT) and masonry contractors in Texas.

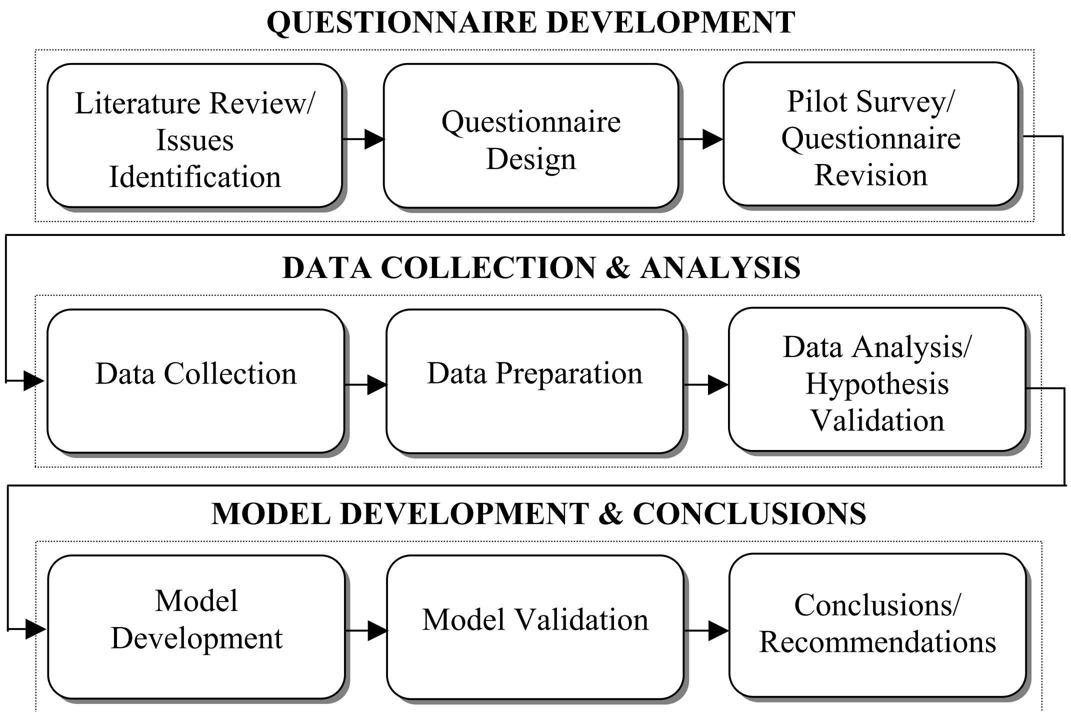


Figure 3.1 Research Investigation Procedure

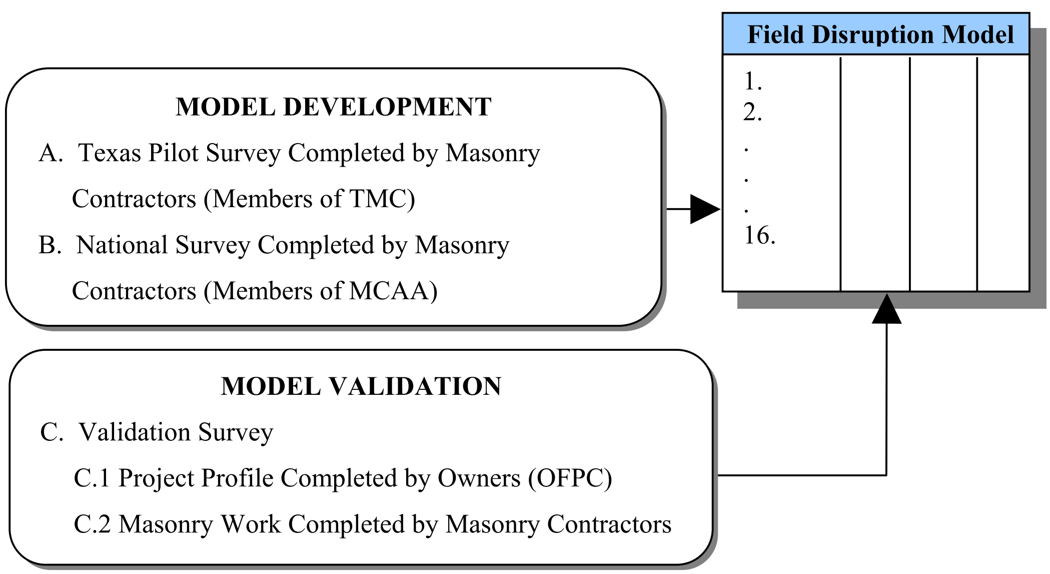


Figure 3.2 Overview of Model Development

3.1 Literature Review and Issues Identification

During the research study, considerable attention was initially directed towards an extensive literature review of the relevant articles as well as identification of significant issues. Particular efforts in the literature review stage were expended to explore three major topics related to this research study, including productivity background, productivity and project performance, and productivity factors. The research then proceeded with the identification and development of relevant issues including field disruptions and standard conditions. These stages are depicted in Figure 3.3 and addressed in the paragraphs that follow.

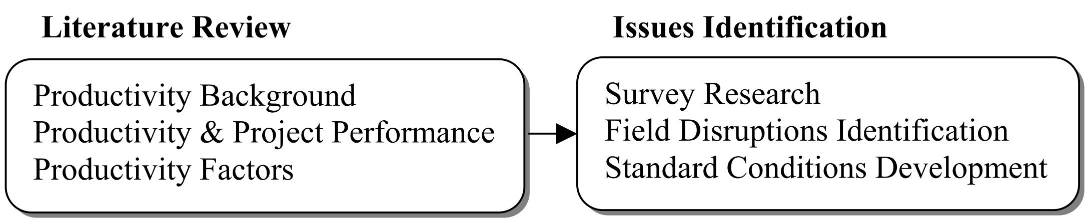


Figure 3.3 Literature Review and Issues Identification Procedure

3.1.1 Literature Review

An extensive literature review was conducted using the resources of UT, CII, and other available references, in order to first identify documented studies on labor productivity. A body of literature related to productivity background was found, and this literature is discussed in Chapter Two. The review focused on several significant topics including variability of productivity, productivity and estimate, loss of productivity and its relative cost, and productivity trends. The next stage of the work was devoted to a study of the significant issues related to productivity and project performance. These topics address how productivity impacts project cost, schedule, quality, and safety. The research then proceeded with the identification of possible productivity factors and their causes, and the effects of productivity loss as well as how to minimize and manage these factors. Several factors and related issues were addressed. Although much literature was found concerning productivity factors, most of the studies involved quantifying productivity loss due to a single factor. Furthermore, few of the publications dealt with the measurement of field disruptions that are beyond the direct control of subcontractors. More importantly, few of the current research studies included direct responses from a large number of masonry construction practitioners in the field. For the purposes of this study, these construction practitioners include owners, chief estimators, or those who are responsible for estimating loss of productivity and its associated damages in masonry construction. The direct responses identified productivity loss due to a variety of field factors normally present at the construction jobsite.

3.1.2 Survey Research

Survey research is defined as a method of observation that involves the collection of data through asking people questions (Fowler, 1993). In this research study, there are two basic methods used to conduct the survey: questionnaires and personal interviews. These two methods were chosen as the most efficient and appropriate data collection techniques for this particular research study. The questionnaire is a self-administered measuring instrument with printed questions to be responded to in writing by an appropriate respondent. It involves either open- or closed-ended questions or both depending upon research purposes. This method is cost- and time-efficient for the researcher while permitting the respondent to answer the questionnaire at his or her convenience. However, it is inflexible and the response rate is generally lower than for other methods such as interviews.

For this study, the questionnaire was mostly distributed by mail, but sometimes by fax and e-mail. The questionnaire development of this study will be discussed in Section 3.2. This research study employed questionnaires to collect data in both the pilot survey and the national survey processes. In the validation process, however, interviews were conducted to collect data by interactively questioning the respondent face-to-face. The interviews included both open- and closed-ended questions, providing more flexibility and explanation for the collection of data. The interview, however, is somewhat more difficult because it requires the researcher to contact the respondent, explain the purpose of the survey, and make an appointment over the phone, as well as to be present at an interview meeting. This method therefore presents a challenge in terms of maintaining time and cost efficiency.

3.1.3 Field Disruptions Identification

A great number of research studies have investigated construction productivity, some of which are related to quantification of field factors. This research aims to add the existing body of research by identifying major negative field disruptions that are beyond the control of masonry contractors. Fifty-one productivity factors were revealed and classified into eight categories as presented in Section 2.3, based on the comprehensive literature review. Due to research time constraints, the researcher felt that considerable attention should be directed toward major field factors frequently discussed in the literature and that often exist on typical construction projects.

To narrow the scope of the study, it was necessary to confine the number of field factors. The 16 renowned field factors initially published by the Mechanical Contractors Association of America (MCA) (1976) were used as the basis for this study. The researcher planned to compare findings from this study with the results from the MCA study, which might help construction practitioners to better estimate productivity loss due to these factors. In accordance with current masonry construction practice, the definition of these factors was originally generated by Dr. Popescu, C. M. and Dr. Grimm, C. T.; both were professors in the Construction Engineering and Project Management program at UT. These factors

These factors and their definition were subsequently modified by the researcher through cooperatively brainstorming with research participants. A number of meetings and contacts were conducted with eight construction practitioners as follows. All of them have at least five years of experience in masonry building construction.

- Two construction managers from OFPC
- One marketing director from MCAA
- One civil engineer from MCAA
- One civil engineer from TMC
- Three chief estimators/owners of masonry contractors in Texas

Once brainstorming discussions with the research participants were conducted, some changes of the names and definitions of these field factors were made. No additional field disruption was added to the list.

3.1.4 Standard Conditions Development

In the construction industry, it is universally accepted that field disruptions can be present at any time with different degrees of adversity. In an effort to deal with these different degrees, it was decided that three condition levels would be established: minor, moderate, and severe. These qualitative condition levels then necessitated the development of standard conditions. A clear specification of the standard conditions was necessary to enable respondents to clearly distinguish the degree of each adverse condition level. Standard conditions referring to three different degrees of severity for each field disruption were initially established by Dr. Popescu, C. M., Dr. Grimm, C. T., and the researcher. The concept of different degrees of severity for productivity factors were previously used in other studies including MCA (1976) and Neil and Knack (1984). Once the standard conditions were created, a brainstorming approach similar to the one used for identification of field disruptions was conducted to further clarify the obtained standard conditions and identify issues related to standard conditions. Perceptions of actual field conditions present in current construction projects dominated the discussions. Minor changes were made to the standard conditions after they were reviewed by the group of construction practitioners that were participating in the field factors development. Straightforward and simple guidelines for each standard condition of 16 field disruptions were then identified. A questionnaire to assess the loss of productivity was developed next, as presented in the following section.

3.2 Questionnaire Design

In the questionnaire design phase, there were three major stages: the development of the questionnaire, questionnaire sample, and computation example. Essential documents for each phase were compiled and put together a survey package to aid questionnaire respondents not only in answering the questionnaire, but also in understanding the uses and needs of this research study. The process of questionnaire design is depicted in Figure 3.4.

Questionnaire Design

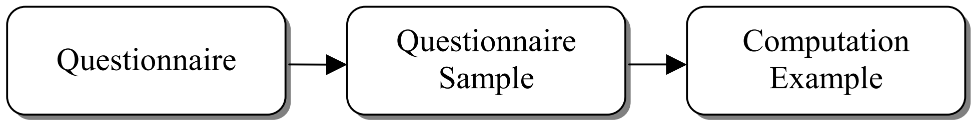


Figure 3.4 Questionnaire Design Process

3.2.1 Organization of the Questionnaire

The completeness of the questionnaire and the number of questionnaire responses were of major concern to the researcher. Equally important, the recognition of respondents regarding the benefits and uses of this research study was also of interest to the researcher. In response to these concerns, the questionnaire design process began with identification of the following criteria:

Questionnaire	**Response Rate**
Accuracy	Time
Relevant	Ease of Completion
Completeness	
Understanding	

To achieve both thoroughness and efficiency, the questionnaire was examined for accuracy and completeness of only relevant questions. The efficiency of the questionnaire, however, did not guarantee a high response rate. It was of equal importance, then, to ensure that the questionnaire allowed the right time frame for respondents to respond and return it to the researcher. Based on the researcher's experience and the pilot survey, the response time was set at twenty minutes, and the respondents were given two weeks to complete the questionnaire. This was reinforced by ease of completing the questionnaire. Simple but effective questions were asked, and different documents in the questionnaire package were printed on pages of distinct color. This was to aid the respondents in correctly answering and efficiently returning the questionnaire.

With respect to the above criteria, the questionnaire package, as presented in Appendix A, was assembled which included a questionnaire, a list of standard conditions, a questionnaire sample, and a computation example. The questionnaire embraced essential questions, while furnishing sample answers in its sample document to aid the project participants in answering the questionnaire. A computation example for an increase of work-hours was produced to help the participants understand the questionnaire and recognize the benefits of this research study. Each document in the questionnaire package is discussed in the following paragraphs.

3.2.2 Questionnaire

The questionnaire design process proceeded on an iterative basis with questions being classified into two main sections: respondent profile, and estimated loss of productivity due to various field disruptions. Questions in the respondent profile were created to collect data such as job position, work and supervisory experience, typical work locations, and contact information. While not directly addressing productivity loss issues, these questions were of value to the research by permitting an analysis of productivity loss issues across a variety of different profiles in different states and regions. It was reasonable to expect that a locality can have an impact to the loss of productivity due to various field disruptions, especially weather or environment.

The second set of questions, concerning loss of productivity, directly targeted the amount of the loss due to 16 field conditions in the three different condition levels, based on the standard conditions. The questionnaire included the list of productivity factors. Each contained three condition levels. Respondents simply furnished the estimated losses of productivity for each field disruption based on the given standard conditions. Therefore, each respondent was expected to provide three values of percentages of productivity loss for each disruption, resulting in a total of 48 values for each field disruption. The losses of productivity for any field disruption were derived from the effects of that specific disruption without taking into consideration the effects of other disruptions. The responses were based on general knowledge and experience of the respondents and not a specific project, so questions regarding project profile were not included. This simple and direct approach was chosen to establish a means of developing productivity loss in the masonry construction industry as a whole.

3.2.3 Questionnaire Sample and Computation Example

The instruction for answering the questionnaire was first explained in the cover letter. To support the criteria goals, a questionnaire sample was established to further demonstrate how to answer the questionnaire. Prior to the pilot study, this questionnaire sample was developed with the estimated productivity losses of each factor randomly generated to eliminate any bias in the data furnished in the sample. A large bold note saying "*Example Only (Not a Guideline)*" was explicitly marked in the middle of the sample page. Finally, a subsequent computation example for an increase of masonry work-hours was developed to assist participants in understanding the survey and to highlight the benefits of the study.

3.3 Pilot Survey and Questionnaire Revision

The next stage of the questionnaire development was devoted to a pilot survey study. This stage consisted of several steps including identification of sources of data, the collection of data, and conclusions. The implementation of lessons learned from this stage significantly benefits the questionnaire development. This process is depicted in Figure 3.5.

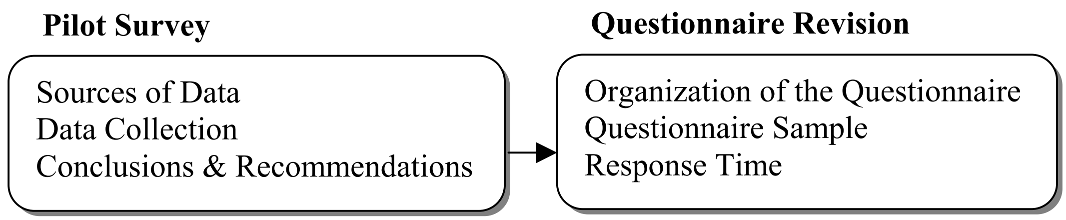


Figure 3.5 Pilot Survey and Questionnaire Revision Process

3.3.1 Pilot Survey

To enhance the questionnaire development process, a pilot survey was conducted from June 1, 2000 to August 30, 2000. Fifty-six questionnaire packages were randomly distributed to masonry contractors in Texas by the TMC. Those participating in the study were TMC members including only facility owners or chief estimators of a constructor. Masonry suppliers and other companies affiliated with the masonry industry were not included in this study. Respondents were expected to complete the questionnaire and mail or fax the response back within four weeks. A total of eleven questionnaires were finally gathered; three of which were incomplete or outliers. The incomplete responses and outliers were removed from the data set leaving a total number of eight in the database. This indicated that the response rate was approximately twenty percent, and the invalid responses were approximately five percent of the total questionnaires distributed. Lessons learned from conducting this pilot survey improved the questionnaire and its process as illustrated in the following paragraph.

3.3.2 Questionnaire Revision

Findings from the pilot study conducted in Texas strengthened the questionnaire package. The improvements were in three major areas: the organization of the questionnaire, the questionnaire sample, and the response time. For the organization of the questionnaire, each supplementary document was printed on paper of distinct color, with the questionnaire in white. This helped respondents to straightforwardly pinpoint the questionnaire form while keeping others for reference. For the questionnaire sample area, a few respondents had failed to follow the instructions provided for the questionnaire sample, the questionnaire sample was therefore improved by enlarging the caution note. The productivity losses data for all factors were still randomly generated, but keeping all values the same. This was to decrease the possibility of using the sample as a guideline. Additionally, the questionnaire would only allow two weeks of response time. This was to encourage respondents to return the questionnaire promptly, in an effort increase the response rate.

3.4 Data Collection and Preparation

Data collection is defined as a process of assembling primary data records for a certain sample or population of observations (Bohrnstedt and Knoke, 1994). In this study, data collection and preparation included the following three main steps:

identification of sources of data, questionnaire distribution, and questionnaire collection, as shown in Figure 3.6.

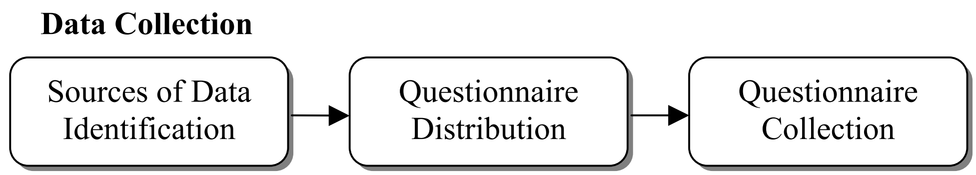


Figure 3.6 Data Collection Process

3.4.1 Sources of Data Identification

Sources of data were first identified in the early stage of the data collection. Some members of MCAA throughout the U.S. were expected to participate in this research study by answering the questionnaire. MCAA in cooperation with the researcher distributed the survey to 950 masonry contractors. Most crew members from these contractors are Union workers. Other members affiliated with the masonry industry such as masonry suppliers, other than masonry contractors, were not included in this research study. Only the owner and chief estimator of the masonry companies were invited to answer the questionnaire.

3.4.2 Questionnaire Distribution and Collection

A total of 950 questionnaire packages were distributed to masonry contractors thoughout the U.S. by MCAA in early September 2000. A two-week turnaround time was required. The TMC members' responses gathered during the pilot survey were also used because all TMC members were also MCAA members and the questionnaire packages of pilot and national surveys were similar, except the questionnaire samples. By the return deadline, a total of 152 of the 950 distributed questionnaires were received, resulting in an approximately 16% response rate. A follow-up contact was conducted over the phone to clarify some ambiguous responses. The most serious concerns presented in the responses were illegible handwriting and some missing data. Less than 20 unclear responses were received and most of them were easily solved after the fact. Table 3.1 shows the frequency distribution of distributed and returned questionnaires. These statistics indicated a slight decrease in the response rate as compared to the pilot study.

Table 3.1 Frequency Distribution of Distributed and Returned Questionnaires

Sources of Data	**TMC**		**MCAA**		**Total**	
Total Questionnaires Distributed	56		894		950	
Total Questionnaires Returned	11	20%	141	16%	152	16%

3.4.3 Data Preparation

Orderly and effective data preparation and management are necessary for successful survey research and data analysis. Figure 3.7 breaks down the data preparation stage for this research study. The common data management program, Microsoft Excel® 2000, was used for the database management, and the Statistical

Package for Social Scientists, SPSS® 9.05 for Windows™, was chosen for the statistical analyses.

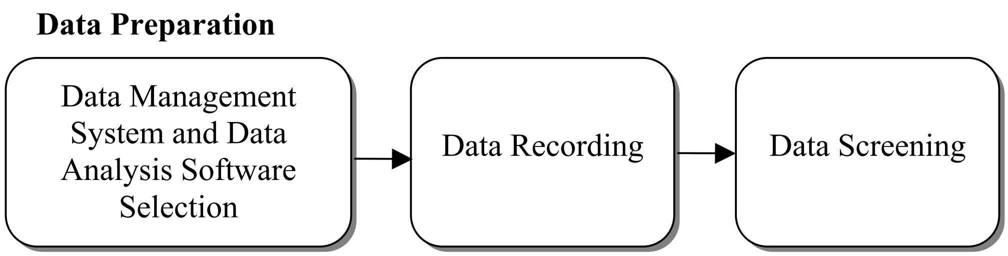


Figure 3.7 Data Preparation Process

The research proceeded with the next step in the data preparation stage, data recording. Survey responses were coded and recorded in Microsoft Excel® spreadsheets, and then directly imported into SPSS® for future analyses. Based on effective research methodologies, five separate databases were established to record and process questionnaire responses. These databases and their contents are presented in Table 3.2.

Table 3.2 Research Databases

No.	Database	Content
1	Participants	Profile data of participants
2	All Data	All responses before the data screening stage
3	Model Data	All responses after the data screening stage
4	Validation Participants	Profile data of participants in the validation survey
5	Validation Data	All responses in the validation survey

In an effort to obtain better data for future analysis, data screening was conducted prior to the data analysis and hypothesis test. In survey research, it is valuable to take a general "look" at data prior to conducting an in-depth analysis, developing a model, and formally testing hypotheses (Fotheringam et al., 2000). The key reasons are to get a "feel" for the data (Fotheringam et al., 2000), and to understand the underlying insights of analysis results. This approach in general is often referred to as exploratory data analysis (EDA) (Turkey, 1977). The simple EDA techniques commonly used in recent years are scatter plots, stem and leaf plots, boxplots, and histograms. In this study, there were a number of underlying objectives for initially "looking" at the data, which refer to some basic questions such as:

- Are there any incomplete data sets?
- Are there any data sets having unusually high or low values?
- Do observations fall into a number of distinct groups?
- What distributions do the variables follow?
- What associations exist between variables?

The researcher continued the study with the data screening phase encompassing three major steps: identifying invalid data sets, identifying bias responses, and detecting outliers and extremes, as shown in Figure 3.8. A summary of the number of data sets being used through the data screening process is presented in Table 3.3.

Data Screening

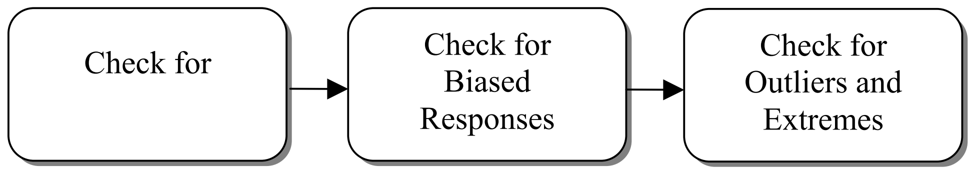


Figure 3.8 Data Screening Process Prior to Further Statistical Analysis

Table 3.3 Summary of the Number of Data Sets During the Data Screening Process

Sources of Data	Total	
Total Questionnaires Distributed	950	
Total Questionnaires Returned	152	
Invalid Data Sets	23	15%
Data Sets After Identifying Invalid Data Sets	129	
Data Sets with Frequency Score of 10 or Higher	13	9%
Data Sets After Identifying Biased Responses	116	76%

Identifying invalid data sets refers to a process of detecting incomplete and questionable responses. A total of 23 invalid data sets, about 15% of the total amount of responses received, were found and consequently discarded from the analysis. Of those, 11 incomplete responses with a significant amount of missing data were uncovered, and 12 questionable responses were found. The questionable responses were results of poor handwriting of participants, low quality fax or copying machines, incorrect responses, and an unreliability of responses. The low quality of hand writing and fax machines during the data collection process prevented the researcher from being accurate in reading and using the answers obtained. The incorrect responses existed where over 100% loss of productivity for a field condition had been entered, and where a summation of losses of productivity of all standard conditions equaled 100% loss of productivity for all, or most, field factors. These were probably due to a misunderstanding of the questionnaire and its purposes. Furthermore, some unreliable responses were due to the fact that they were almost identical to those given in the questionnaire example. As a result, 129 data sets advanced to the next step of data screening, determining biased responses. These data sets are presented in a tabular format in Appendix C.

The research study proceeded with checking for biased responses. The biased responses refer to questionnaire responses with several outliers and extremes, which can significantly skew the distribution curve. This step of data screening was performed using the boxplot option from SPSS® 9.05 for Windows™. Once all boxplots were generated and all outliers and extremes were identified, a frequency score (F.Score) was used as the criteria to determine which data sets should be discarded (Cho, 2000). A frequency score was calculated combining the number of outliers and extremes from a data set. Since outliers and extremes skew the distribution curve to relatively different degrees, different weights were attributed to the outliers and extremes as shown in Table 3.4. A frequency score for each field condition of each disruption was then computed using Equation 3.1 (Cho, 2000).

Frequency Score = 3 x No. of Extremes + 1 x No. of Outliers (Equation 3.1)

Table 3.4 Data Screening Variables and Weights (Cho, 2000)

	Description	Weight
Extremes	Values that are *more than 3 IQR's* from the end box	3
Outliers	Values that are *more than 1.5 IQR's, but less than 3 IQR's* from the end box	1

Based on the boxplot analysis and the frequency score calculation, a total of 13 data sets with a frequency score of 10 or higher was discovered and also removed, leaving a total of 116 valid data sets for the next data screening step, checking for outliers and extremes.

The researcher identified outliers and extremes through the use of the boxplot option from SPSS® 9.05 for Windows™. A total of 48 boxplots was generated for 16 disruptions containing three standard conditions, and then all outliers and extremes were identified and discarded. As a result, there was a total of 116 data points or less for each standard condition of field disruptions. A summary of the remaining data for each standard condition for all disruptions is provided in Section 4.5 after a detailed discussion about the process of checking for outliers and extremes.

3.5 Data Analysis and Hypothesis Validation

Statistical analysis permits researchers to achieve tentative conclusions regarding the existence and strength of any relationship of concerns (Bohrnstedt and Knoke, 1994). To successfully attain thorough conclusions, it is essential to understand statistical techniques and properly interpret the statistical results (Fowler, 1993). As such, the following sections demonstrate various statistical techniques employed in this research study.

3.5.1 Descriptive Statistics

Descriptive statistics are employed to summarize and describe data, transforming large groups of numbers into more manageable form. It can be used in the form of tables or graphs, providing a summary picture of data or describing the data with numerical measures (Agresti and Finlay, 1997). In this research study, descriptive statistics provided general information such as averages, proportions, and frequency counts, all of which related to the trend and distribution of productivity loss. These statistics were classified by the variables taken from the respondent profile data.

3.5.2 The Boxplot

The boxplot is a graphical display that summarizes information about the distribution of values based on the median, quartiles, and extreme values (SPSS® 9.05

for Windows™). Figure 3.9 depicts an annotated sketch of the boxplot. The horizontal line across the box represents the median showing the central tendency or location. The median of a variable is "simply the middle value if the variable is tabulated in ascending order and *n* is odd" (Fotheringham et al., 2000), where *n* is defined as the number of values. If *n* is even, the median is the midpoint of the two middle values. The lower and upper boundaries of the box are the 25th and 75th percentiles, respectively, indicating that 50% of the values fall within the box.

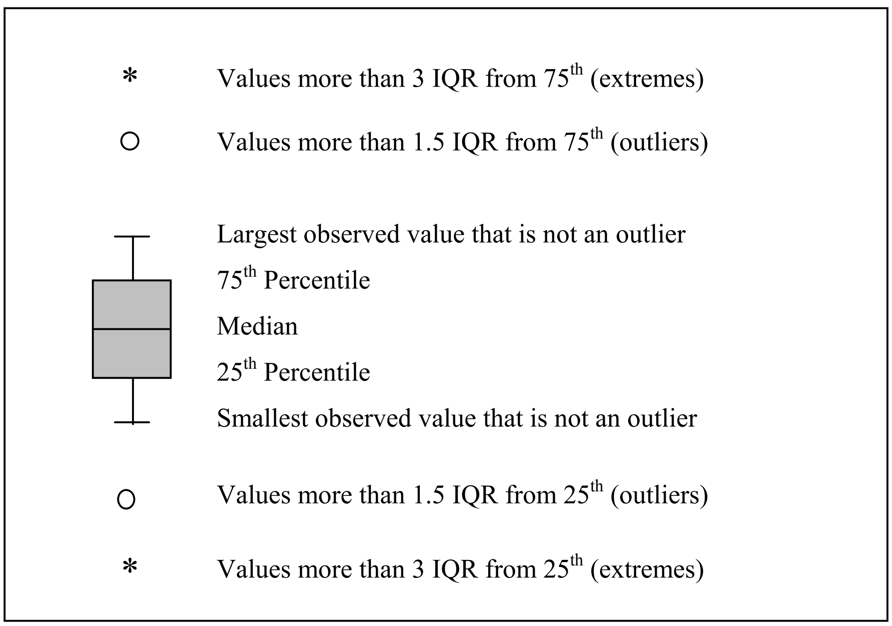


Figure 3.9 Annotated Sketch of the Boxplot (Adopted from Cho, 2000)

The length of the box refers to the inter-quartile range (*IQR*) indicating the spread or variability of the middle 50% of data. The *IQR* is defined as shown in

Equation 3.2. The lines that extend from the box to the highest or lowest values are known as whiskers. The outliers and extremes are unusually small or large values by comparing with the remainder of those values, which skews the distribution. The outliers and extremes are defined as presented in Equations 3.3 and 3.4, respectively.

$$IQR = Q3 - Q1 = \textit{inter-quartile range} \qquad \text{(Equation 3.2)}$$

$$Q3 + STEP \leq \text{Outliers } (yi) < Q3 + 2STEP \quad \text{or} \qquad \text{(Equation 3.3)}$$

$$Q1 - 2STEP < \text{Outliers } (yi) \leq Q1 - STEP$$

$$\text{Extremes } (yi) \geq Q3 + 2STEP \quad \text{or} \qquad \text{(Equation 3.4)}$$

$$\text{Extremes } (yi) \leq Q1 - 2STEP$$

Where: $Q3 = 75^{th}$ percentiles,

$Q1 = 25^{th}$ percentiles,

$STEP = 1.5\ IQR$, and

$yi = i$th observation of input cases, $i = 1, \ldots, n$.

One very useful property of the boxplot is that it is relatively flat, so several boxplots may be stacked horizontally (Fotheringam et al., 2000). This is helpful for comparing the distributions of several different variables measured on the same scale or several variables that have been standardized.

3.5.3 Analysis of Variance

An analysis of variance (ANOVA) involves methods for comparing means of the various groups (Agresti and Finlay, 1997). One-way analysis of variance is one of the most common analyses that can simultaneously compare the mean responses of several groups for quantitative response variables. This analysis uses a significance test, called the *F-distribution*, for identifying evidence of differences among the population means. There are three basic assumptions for the test and are as follows (Agresti and Finlay, 1997; Wonnacott and Wonnacott, 1969):

- The population distributions on the response variable are normal for all groups.
- The standard deviations of the population distributions are equal for all groups.
- Independent random samples are selected from populations of all groups.

The *F-statistic* is the ratio of two estimates, the *between*- and *within*-groups estimates, of the population variance of the variables in the groups. The nominator estimate uses the variability *between* each sample mean and the overall sample mean, whereas the denominator estimate uses the variability *within* each sample. The null hypothesis ($\mu_1=\ldots=\mu_g$) is false when the *F-statistic* is considerably larger than 1.0, where g denotes the number of groups and μ refers to the mean of the response variable for a population. A p-value is the probability that the *F-statistic* is at least as large as the observed *F* value; that is, the larger the *F-statistic*, the smaller the p-value (Agresti and Finlay, 1997).

3.5.4 Validation of the Research Hypothesis

The hidden relationships between the responses were explored through statistical tests. The outcomes of these tests were expected to reveal in depth the problems related to loss of productivity, and to provide ideas on how management could enhance their site conditions in order to correct the problems. In this study, the researcher hypothesized that there were statistically significant differences among percentages of productivity loss for different severity levels of field conditions in a masonry building construction project. Thus, an assessment of the differences was necessary as a validation of the survey questionnaire. One-way ANOVA was conducted through the use of SPSS® 9.05 for Windows™ and the *F-statistic* and p-value were then calculated to test statistically significant differences of different standard conditions.

3.5.5 Level of Significance and Reporting the Test Results

The level of significance, denoted as α, is the maximum probability of rejecting a null hypothesis when its values fall into the critical region (Cooper and

Weekes, 1983). Significance levels commonly used in statistical research are 0.05 and 0.01 (Agresti and Finlay, 1997; SPSS® 9.05 for Windows™). A very low level of significance can minimize the Type-I error, wrongly rejecting the null hypothesis when it is actually valid. However, it also increases the probability of making another kind of mistake, a Type-II error, accepting the null hypothesis when in fact it is not.

The level of significance establishes a particular range of extreme values, typically referring to the critical region. Values not in the critical region constitute the acceptance region. With reference to the known distribution, the test statistic of a null hypothesis is compared with the critical value at a specific significance level. If the test statistic is greater than the critical value, the null hypothesis can be rejected. By the same token, if a probability value, commonly known as a p-value, is less than the significance level set for the test, the null hypothesis can be rejected. In the statistical tests, the statistical analysis program employed in this research study provided the p-values for significance tests. In this study, the researcher felt that the 0.05 level of significance was appropriate, and thus the test results were reported based on these values at the 0.05 level of significance.

3.5.6 Missing Data

Missing data commonly occurs when a questionnaire respondent decides not to answer a question or when the answer given by the respondent has been discarded (Kim, 1993). In statistical analysis, there are two ways to handle missing data: list- or pair-wise (Norusis, 1982). The list-wise manner excludes from analysis all data taken from the questionnaires with any missing data. On the other hand, the pair-wise manner excludes from analysis only the missing data, and includes all other valid data taken from the same questionnaires. In this study, the list-wise method was used for the analysis in the data screening process, resulting in a total of 23 incomplete responses which were discarded.

3.5.7 Limitation of Data Analysis

This research study contained some limitations in terms of the methodology and the data collection. The major limitation was that the standard conditions provided in the questionnaire were only guidelines, not solid criteria. Although the guidelines helped to distinguish the degree of field disruptions considered, some field activities were excluded in the conditions. The second limitation was that the sources of data for analyses were collected through a survey rather than by way of an empirical study of actual productivity information. This method introduced subjective information to the study. Nevertheless, due to the great number of responses and the orderly and effective model validation, the model developed is truly of value to masonry practitioners and researchers for references.

The next limitation was that the selection of validation projects was based on the companies' voluntary effort, not on a random sample of a known population. The companies may have selected projects with a bias toward successful projects, resulting in an influence on the evaluation results. Additionally, in the evaluation process, collecting data from some completed projects required the respondent to think back and evaluate the field conditions during the project execution. Since it may be difficult to remember precise details of the field disruptions, the evaluation tests may produce slightly inaccurate results regardless of how complete their project document was. As a result, this method of data collection may have lead to some bias in the model evaluation.

3.6 Model Development

The main objective of the model development in this research study is to present the final research results for practical use in the masonry construction industry. The following criteria, therefore, were developed in response to this objective.

Model

Accuracy

Completeness

Ease of implementation

Understanding

With considerable influence from these criteria, a simple yet effective model for practical use in today's masonry construction was established. Primarily based on the descriptive analysis results, the model showed means and medians of productivity loss due to all 16 field disruptions with three standard conditions. The model also included low and high values of plausible productivity loss which occurred from the sample data collected. A copy of the standard conditions was also attached to the model to establish the definitions of the degrees of field disruptions. Computation examples regarding the use of this model were provided. The complete set of the model is expected to be useful for masonry practitioners in managing and estimating loss of productivity due to the presence of these field disruptions.

3.7 Model Validation

After the model was generated, considerable attention was directed toward the model validation process. The primary goal of this process was to determine the accuracy of the developed model by comparing model results to estimates from validation projects. In an effort to reach this goal, an interview was conducted to collect data by interactively questioning some participants face-to-face. Four major phases in the model validation process are shown in Figure 3.10.

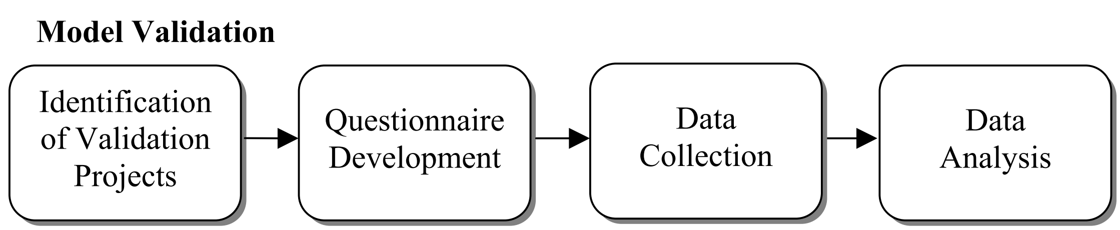


Figure 3.10 Model Validation Phases

3.7.1 Identification of Validation Projects

The first phase of the model validation involved an identification of construction projects used to validate the model. In an effort to obtain an appropriate validation project, several criteria were compiled as follows.

Validated Projects

Projects should be located in the United States

Projects have been recently constructed or are to be completed within 3 years.

Project type is limited to building projects.

A total of nine projects in Texas were selected by two Resident Construction Managers of the OFPC at UT, and five of them yielded all of the above criteria. These projects, located in Austin, Texas, were chosen to validate the model based on the masonry contractors' voluntary efforts. Two projects were currently being built, while the others had been completed.

3.7.2 Questionnaire Development

Particular attention was paid to developing a validation questionnaire to facilitate the subsequent interview. Criteria similar to those applied to the questionnaire in the national study were of interest to the researcher; the validation questionnaire was checked for accuracy, understanding, and completeness of relevant and essential questions. A time frame of less than one hour was considered to be appropriate for each interview session.

In accordance with the criteria, the validation questionnaire, as presented in Appendix B, was generated to validate the model. The questionnaire contained both open- and closed-ended questions and provided for more flexibility and explanation in the data collection. The validation questionnaire proceeded with questions being classified into two main parts: participant and project profiles, and masonry field disruption data. Questions on participant profile were established to collect participant data, including job position, masonry work experience, and contact information. Questions on project profile were created to collect project data, such as the project type, project location, project cost, and project schedule. These data were necessary to this research study in order to understand the nature of the validation projects. Based on the list of field disruptions and standard conditions, the second part of the validation questionnaire involved masonry field disruptions and work-hours of the masonry crew during a certain time frame. For a more comprehensive understanding of the project, additional questions related to the nature of the project were also added. These questions encompassed costs of the project and masonry work, schedule of the project and masonry work schedule, and change orders of the project and masonry work.

3.7.3 Data Collection

The researcher first contacted two Resident Construction Managers of the OFPC at UT (owner organization's representatives) to request information regarding nominated projects and masonry contractors' contacts. Several subsequent interviews with the OFPC representatives were conducted to complete the first part of the validation questionnaire, which was developed to obtain essential project information and to obtain contact information of masonry contractors. Six masonry contractors' representatives were suggested by OFPC representatives, and these six were associated with a total of ten nominated projects that yielded the criteria for validation projects. Similar to the data collection process in both the pilot and national studies, those participating in the evaluation process were owners or chief estimators of their masonry organization.

Once the contact information of masonry contractors' representatives had been obtained, the researcher proceeded with contacting to the representatives of the nominated projects by phone. During the phone discussion, the representatives were presented with the purpose of the survey and study, and if interested, an interview date was set up. Out of six, three masonry contractors' representatives, associated with five projects, agreed to participate in this research study and set up an interview. All interviews were conducted at the participants' offices. Based on the questionnaire developed, the interviews were conducted face-to-face, while the participants followed a copy of the questionnaire. This would facilitate the interview by providing flexibility in further questions or clarifications as the interview progressed. After the interviews, the data from the interviews were then inputted in the Microsoft Excel® 2000 worksheets for further analysis. A summary of the data collected in the validation process are presented in Appendix D.

3.7.4 Data Analysis

The analysis results were used to determine the accuracy of the developed model used to quantify loss of productivity due to various field disruptions. This was done through the use of two analysis approaches. The first one was to identify differences in the estimated percentages of productivity loss computed from the model and the actual percentages of productivity loss computed from the data collected in the model validation process. This approach can present the overall accuracy of the model based on the five validation projects.

The second approach was to determine whether the actual percentages of productivity loss of the validation projects fell within an *IQR* which was constructed based on the raw data collected in the model development process. The *IQR* showed the spread or variability of the middle 50% of the raw data used to develop the model. Once the *IQR*s of all five validation projects were examined, they were compared with the actual percentages of productivity loss of the validation projects. This determined whether the actual percentages of productivity loss fell within the *IQR* or how far the actual percentages of productivity loss fell out of the range, and thereby determined the accuracy of the model.

3.8 Conclusions and Recommendations

After the model validation was completed, the final phase of the research investigation was to explain the conclusions and recommendations. This phase highlighted significant research findings, as well as the research objectives and hypothesis. Added values and lessons learned from this research study were presented for further research efforts. These conclusions and recommendations will be included in Chapter Seven.

3.9 Summary

This chapter detailed the research methodology conducted to develop and validate the field disruption model. An overview of several phases of this research study was presented, including the questionnaire development, the data collection and analysis, and the model development and validation phases. This study was conducted through survey research by distributing the questionnaire package throughout the U.S. Raw data acquired from each questionnaire was input into a Microsoft Excel® spreadsheets, and then converted into SPSS® for further analyses. Several statistical techniques such as descriptive analysis, the boxplot, and ANOVA were employed to conduct the data analyses, as well as to verify the research hypothesis. The next chapter discusses in detail the development of the survey package and the data screening process for the national survey.

CHAPTER IV

SURVEY PACKAGE AND DATA SCREENING PROCESS

This chapter details the steps involved in developing the research survey package and screening the data prior to further analysis. Specifically, the chapter outlines the significant field disruptions and standard conditions for masonry construction based on an extensive literature review and a number of brainstorming sessions by research participants. The field disruptions and standard conditions are part of the questionnaire package. This chapter presents the results of the descriptive analysis, highlighting background information of the project participants and the relevant projects. The post-survey data screening process is also discussed in detail to identify invalid data sets and outliers and extremes.

4.1 Field Disruptions

Sixteen field disruption factors originally published by the Mechanical Contractors Association of America (MCA) (1976) were used in this study. Other vital publications to this research study include Borcherding and Alarcon (1991) and National Electrical Contractors Association (NECA) (1976). The organizations involved in the identification stage include personnel from the Mason Contractors Association of America (MCAA), Texas Masonry Council (TMC), Office of Facilities Planning and Construction (OFPC), and masonry contractors in Texas.

MCAA was considered to be the most influential organization in development of this study because members of the MCAA were expected to participate in this study and part of the research results was anticipated to be published in their publication. The field disruptions and their definition were subsequently modified through cooperatively brainstorming with research participants to determine possible field factors. As a result, a total of 16 major field disruptions based upon the initial MCA study and definitions developed by Dr. Popescu, C. M., Dr. Grimm, C. T., and the researcher were presented and defined as shown in Table 4.1.

These field disruptions are major productivity factors that are commonly beyond the control of masonry contractors. The impact of these field factors can result in significant productivity loss consequently affecting on project performance. These field factors can be a product of numerous circumstances present at the construction field such as changes, surrounding work activities, and management practices. Some factors are direct sources of productivity loss, while some are indirect sources (Borcherding and Alarcon, 1991). Several authors as shown in Table 4.2 provide guidance in accounting for the effect of these field factors. A summary of current relevant literature and detailed definitions of the field disruptions will be discussed in Chapter Five.

Table 4.1 List of the Sixteen Major Field Disruptions

No.	Field Disruptions	Description
1	Congestion	Change prohibits use of optimum crew size including physically limited working space and material storage.
2	Morale and Attitude	Change involves excessive inspection, multiple change orders and rework, schedule disruption, or poor site conditions.
3	Labor Reassignment	Change demands rescheduling or expediting, and results in lost time to move out/in.
4	Crew Size Change	Change increases or decreases optimum crew size resulting in inefficiency or workflow disruption.
5	Added Operations	Change disrupts ongoing work due to concurrent operations.
6	Diverted Supervision	Change causes distraction of supervision needed to analyze and plan changed work, stop and re-plan ongoing work, or reschedule work.
7	Learning Curve	Change causes workers to lose time while becoming familiar with and adjusting to new work or a new environment.
8	Errors and Omissions	Change causes time lost due to mistakes engendered by changed circumstances.
9	Beneficial Occupancy	Change requires the use of premises by owner prior to work completion, restricted work access, or working in close proximity to owner's personnel or equipment.
10	Joint Occupancy	Change requires work to be done while other trades who were not anticipated in the bid occupy the same area.
11	Site Access	Change requires inconvenient access to work area, inadequate workspace, remote materials storage, or congested worksite.
12	Logistics	Change involves unsatisfactory supply of materials by owner or general contractor, causing inability to control materials procurement, and delivery and re-handling of substituted materials.
13	Fatigue	Change involves unusual physical exertion causing lost time when original plan resumes.
14	Work Sequence	Change causes lost time due to changes in other contractors' work.
15	Overtime	Change requires overtime causing physical fatigue and poor mental attitude.
16	Weather or Environment	Change involves work in very cold or hot weather, during high humidity or in a dusty or noisy environment.

Table 4.2 List of the Major Field Disruptions and References

No.	Field Factors	Related References
1	Congestion	MCA, 1976; Army Corps of Engineers (CORPS), 1979; Neil and Knack, 1984; Contractor's Consultants Corporation (CCC), 1984
2	Morale and Attitude	MCA, 1976
3	Labor Reassignment	MCA, 1976; CCC, 1984
4	Crew Size Change	MCA, 1976; CORPS, 1979; CCC, 1984
5	Added Operations	MCA, 1976
6	Diverted Supervision	MCA, 1976
7	Learning Curve	O'Connor, 1969; MCA, 1976; Lorenzoni, 1978; CCC, 1984; Yiakoumis, 1986
8	Errors and Omissions	MCA, 1976
9	Beneficial Occupancy	MCA, 1976
10	Joint Occupancy	MCA, 1976
11	Site Access	MCA, 1976
12	Logistics	MCA, 1976; Borcherding et al., 1980; Borcherding and Garber, 1981; Neil and Knack, 1984; Thomas et al., 1989
13	Fatigue	MCA, 1976
14	Work Sequence	MCA, 1976; Thomas and Oloufa, 1995
15	Overtime	Edmonson, 1974; MCA, 1976; Business Roundtable (BRT), 1980; Neil, 1982; Neil and Knack, 1984; NECA, 1989; Thomas, 1992; Thomas and Raynar, 1994
16	Weather or Environment	Grimm and Wagner, 1974; NECA, 1974; MCA, 1976; Koehn and Brown, 1985; Thomas and Yiakoumis, 1987

In this research study, care was taken to describe each disruption responsible for productivity loss. However, some disruption descriptions may not contain all the details involved in every case. Consequently, the answers from respondents regarding quantitative effects of the factors may vary based on the individual contractor, its crew and the job. For instance, the weather or environment factor does not refer to change involving work under precipitation, even though precipitation could be classified into this category. This might generate a misinterpretation of the disruptions' definition. Additionally, each field disruption can be present on a construction field with differing degrees of severity. To enhance an understanding of these disruptions, three severity levels of standard conditions of field disruptions were identified, and are presented in the next section.

4.2 Standard Conditions

In order to measure productivity loss in a construction field, this study established standard conditions illustrating the difference among three condition levels of field disruptions. A literature review relating quantification of productivity loss showed that some widely accepted models in the construction industry had failed to define standard field conditions resulting in confusion in practical use. In this study, therefore, the key purpose of the standard conditions was to enable questionnaire respondents to have a uniform perspective of the gravity of field disruptions, as well as to clarify the definition of the field disruptions.

Particular efforts were made in the development of standard conditions toward the principal objective that the standard conditions must contain an effective and practical manner of information that clearly offers a picture of different severity degrees. Standard conditions referring to three different degrees of severity for each field disruption were determined as shown in Table 4.3. For instance, for the first factor called congestion, the minor condition involves one additional crew or trade working in the same area once a week, and the moderate condition involves an additional crew or trade working in the same area 2-3 times per week. The severe condition refers to an additional crew or trade working in the same area more than three times per week. Detailed descriptions of these standard conditions will be discussed along with research results in Chapter Five.

Table 4.3 Standard Conditions of Field Disruptions

No.	Field Factors	Standard Field Conditions		
		Minor	**Moderate**	**Severe**
1	Congestion	An additional crew/contractor working in the same area 1 day/week	Additional crews/contractors working in the same area 2-3 days/week	Additional crews/contractors working in the same area everyday
2	Morale and Attitude	Less than 3 inspections/week, average 1 hour each	Daily inspection, 1-2 hours each	Full time inspection
3	Labor Reassignment	Crews move once a week between job areas	Crews move 2-3 times/week between job areas	Crews move almost daily between jobs
4	Crew Size Change	Crew size changes once/week	Crew size changes 2-3 times/week	Crew size changes almost daily
5	Added Operations	Work disrupted once/week	Work disrupted 2-3 times/week	Work disrupted almost daily
6	Diverted Supervision	2 times/week, 1-2 hours	Daily, 1-2 hours	Daily, 4 hours or more
7	Learning Curve	Once a week	2-3 times/week	Daily
8	Errors and Omissions	Every 2 weeks or more	Every week	Every 1 or 2 day(s)
9	Beneficial Occupancy	Punch list work	Punch list and new work one week prior to the original completion date	Many crews and overtime a few days prior to the original completion date
10	Joint Occupancy	Facility partly occupied, one trade working	Facility partly occupied, 2-3 trades working in the same area	Facility in operation, work on limited shifts
11	Site Access	4 days/week, < 25 yards to materials storage	2-3 days/week, 25-50 yards to materials storage	Once/week, > 50 yards to materials storage
12	Logistics	1 re-handling lifting, 4 days/week material availability	2 re-handling lifting, 2-3 days/week material availability	> 3 re-handling lifting, limited time
13	Fatigue	Once/week	2-3 times/week	Every day for more than 1 week
14	Work Sequence	One trade, one change/week	2 trades, 2-3 changes/week	Multiple trades, many changes
15	Overtime	< 5 hours/week, 1-2 consecutive weeks	5-10 hours/week, 3-5 consecutive weeks	> 10 hours/week, > 5 consecutive weeks
16	Weather or Environment	Expected temp. +5F in summer or -5F in winter	Expected temp. +10F in summer or -10F in winter	Expected temp. +15F in summer or -15F in winter

4.3 Research Questionnaire

Particular efforts were called for in the development of the research questionnaire package. Issues related to the effectiveness of the questionnaire and the response rate had substantial bearing not only on the questionnaire package itself, but also on the data collection process as a whole. Certain criteria had been made toward these concerns as discussed in Section 3.2. As a result, there were four essential documents included in each questionnaire package as shown below.

- Questionnaire
- Definitions of Standard Field Conditions
- Example of Questionnaire Response
- Computation Sample

The questionnaire was intentionally developed to obtain a respondent profile and data regarding loss of productivity. The first part of the questionnaire requested general information such as the respondent's position, office location, and experience in masonry construction. The second part of the questionnaire directly inquired about the amount of productivity loss due to 16 field factors with 3 conditions each. The questionnaire was later printed on one page of white paper whereas other documents were in yellow, so participants could easily identify which document must be returned. A portion of the questionnaire is shown in Figure 4.1.

No.	Changed Conditions	Estimated percentage of productivity loss (%), if the change is … (0% to 100% in each column)		
		Minor	**Moderate**	**Severe**
1	**Congestion**: Change prohibits use of optimum crew size including physically limited working space and material storage.			
2	**Morale and Attitude**: Change involves excessive inspection, multiple change orders and rework, schedule disruption, or poor site conditions.			
3	**Labor Reassignment**: Change demands rescheduling or expediting, and results in lost time to move out/in.			

Figure 4.1 Part of Research Questionnaire

The participants were expected to furnish estimated productivity loss for each condition of field factors based on the given standard field conditions. The answers were primarily based on knowledge and experience of the respondents or a productivity database of his or her company in general, not a specific construction project. The participants were informed that estimates of productivity loss of any disruption should be derived from the effects of that specific disruption with no effects of other disruptions involved. Based on the standard field condition given, this approach would clearly yield a measure of loss of productivity due to several field conditions for the masonry industry. The second document included in the questionnaire package was the standard field conditions described earlier in this chapter. The standard conditions of field factors were intentionally configured to provide all participants with clear guidelines and qualitative definitions of minor, moderate, and severe conditions, so that estimates could be made as accurately as possible. The standard field conditions are presented in Table 4.3.

Previous research using this kind of survey study resulted in a number of invalid responses. Particular attention was thus placed on the development of the third questionnaire document, an example of questionnaire response. This was included in the questionnaire primarily to minimize invalid responses, not as a guideline. Random numbers were generated as estimated losses of productivity and these were similar for all field disruptions. A caution regarding the purpose of this questionnaire example was highlighted in large type in the middle of the sample page. Part of the sample is shown in Figure 4.2.

Fill All Boxes with the Percentage of Productivity Loss

Example Only (Not a Guideline)

No.	Changed Conditions	**Estimated percentage of productivity loss (%), if the change is …** (0% to 100% in each column)		
		Minor	**Moderate**	**Severe**
1	**Congestion**: Change prohibits use of optimum crew size including physically limited working space and material storage.	4	9	15
2	**Morale and Attitude**: Change involves excessive inspection, multiple change orders and rework, schedule disruption, or poor site conditions.	4	9	15
3	**Labor Reassignment**: Change demands rescheduling or expediting, and results in lost time to move out/in.	4	9	15

Figure 4.2 Part of the Example of Research Questionnaire

To permit the participants to understand the questionnaire and highlight the use of the study results, a computation sample was generated based on data in the questionnaire example. The sample demonstrates steps for computing work-hours lost due to one field disruption as shown in Figure 4.3. More details of how to implement the actual research results will be further explained in Chapter Six.

The complete questionnaire package was compiled and sent to participants in early September 2000, with a response time frame of two weeks from September 15, 2000 to September 29, 2000. A total of 152 questionnaires were finally collected and used for the descriptive analysis presented in the next paragraphs.

A. Estimated masonry hours 1,000
B. Actual masonry hours (payroll) 1,200
    Therefore, total work-hours lost (B-A) 200
C. A site factor causing masonry-hours lost, if your project has the following condition
    (selected by a masonry contractor)
    From sample survey data
    No. 11 Site Access, Moderate Change 9%
D. Computation
    Work-hours lost due to the changed condition = 1,000 x (0.09) = 90 hours
    Total work-hours lost (from B) = 200 hours
    Lost due to unexpected conditions or subcontractor = 200 – 90 = 110 hours

Figure 4.3 Computation Sample Furnished in the Questionnaire Package

4.4 Descriptive Analysis

One of the most challenging concerns in research survey is a survey response rate. Particular efforts were therefore called for in the data collection stage of this research study. Of approximately 1,000 members of MCAA, 950 are masonry contractors and about 150 are companies affiliated with the masonry industry. The owner and chief estimator of masonry companies were the targeted respondents in the study. In total, 950 questionnaire packages were distributed to its members throughout the U.S. Due to the fact that all TMC members were also members of MCAA, it was ensured that responses from TMC were included in those from MCAA. A total of 152 questionnaires were returned from 40 states, creating approximately a 16% response rate. Table 4.4 shows the number of respondents based on the physical location of the company's main office. Figure 4.4 shows the percentages of total questionnaires returned. Detailed information about the distributed and returned questionnaires is presented in Appendix E.

Table 4.4 Summary of Questionnaire Responses by State

State	**AL**	**AR**	**AZ**	**CA**	**CO**	**CT**	**DE**	**FL**	**GA**	**HI**
No. of Participants	1	0	2	15	5	1	0	3	1	1
State	**IA**	**ID**	**IL**	**IN**	**KS**	**KY**	**LA**	**MA**	**MD**	**ME**
No. of Participants	1	1	14	5	0	3	1	3	5	1
State	**MI**	**MN**	**MO**	**MS**	**MT**	**NC**	**ND**	**NE**	**NH**	**NJ**
No. of Participants	6	2	6	0	1	2	0	2	1	1
State	**NM**	**NV**	**NY**	**OH**	**OK**	**OR**	**PA**	**SC**	**SD**	**TN**
No. of Participants	0	1	5	9	0	3	7	3	0	3
State	**TX**	**UT**	**VA**	**VT**	**WA**	**WI**	**WV**	**WY**		
No. of Participants	15	2	7	1	3	7	1	1		

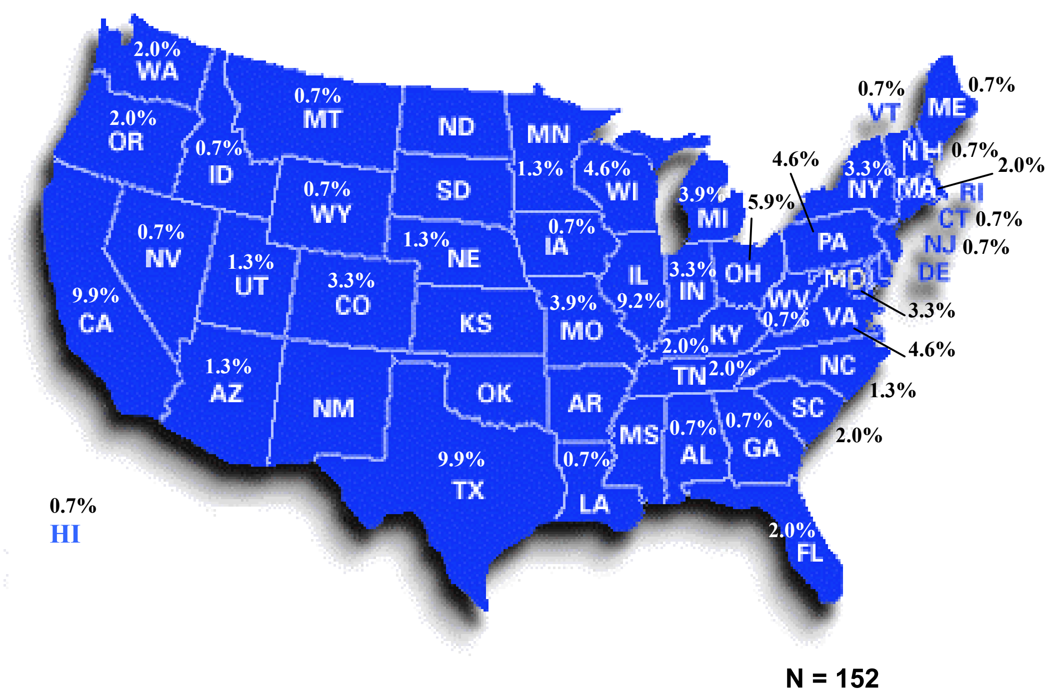


Figure 4.4 Percentages of Questionnaire Responses

Figure 4.5 categorizes the project types that participating companies encompass. As is to be expected from the masonry industry, almost 90% of the survey participants are involved in industrial and commercial projects. Analysis findings reveal that approximately 61% engage in educational and governmental projects, and about 40% are experienced with residential and renovation projects. The total sale volume per year of the companies is also shown in Figure 4.6. The evidence from a descriptive analysis shows that almost 90% of masonry companies joining this study have less than a 5-million-dollar total sale volume per year. Only four percent of these participants have over 10-million-dollar of revenue per year. Figure 4.7 summarizes the number of years of experience in masonry construction projects. An analysis shows that more than 70% of the survey participants have over 20 years of experience, while about two percent of those have less than five years of experience.

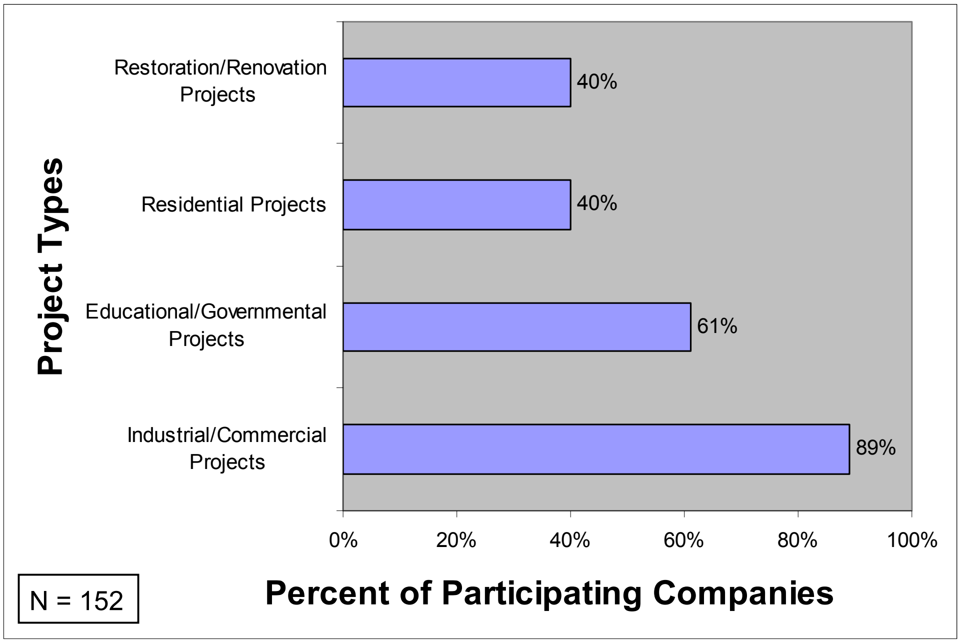


Figure 4.5 Project Types of Participating Companies

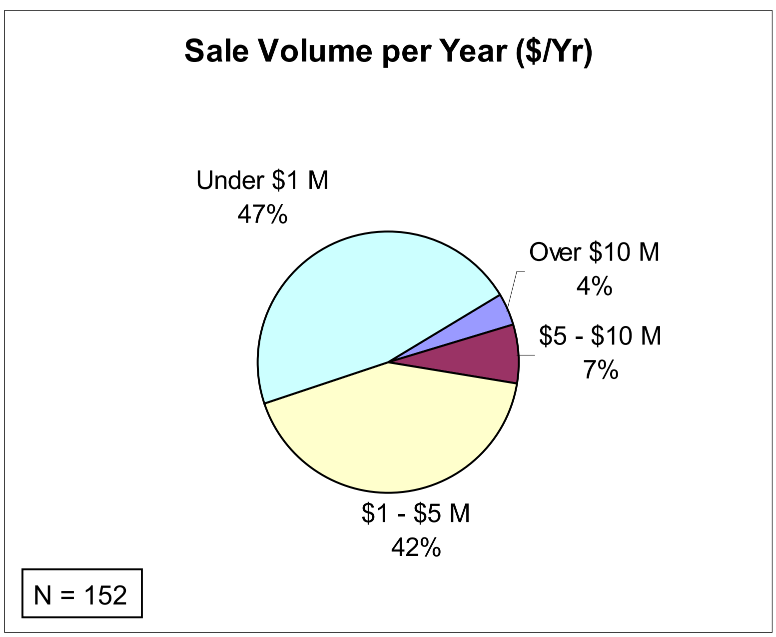


Figure 4.6 Respondents' Total Sale Volume per Year

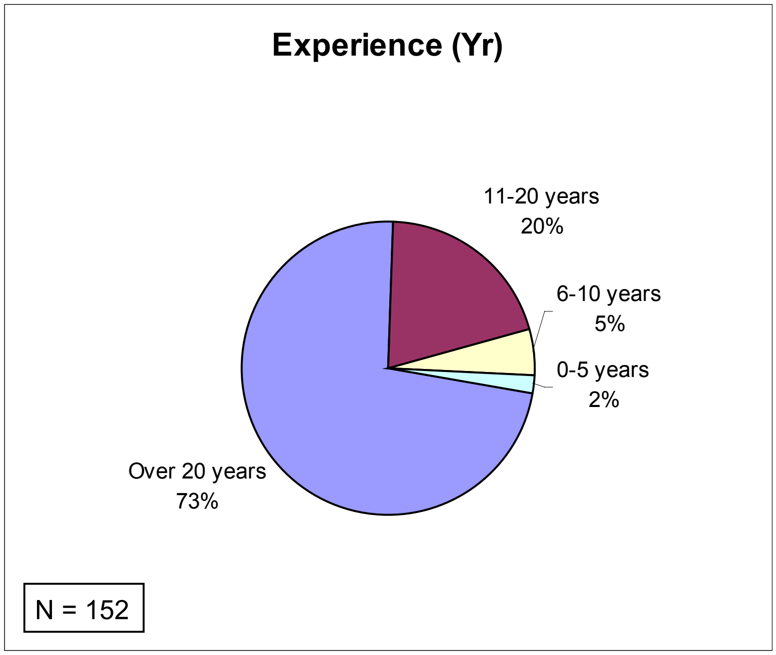


Figure 4.7 Participants' Years of Experience

4.5 Data Screening

Out of 950 questionnaires distributed, a total of 152 questionnaires was received. Significant efforts were made to conduct accurate data screening on these 152 questionnaires. The data screening phase involved three major steps, which were to check for invalid responses, to identify biased responses, and to exclude outliers and extremes. After checking for invalid data sets, a total of 23 invalid data sets was removed from the database. Those consisted of incomplete and questionable responses. The next step was to check for biased responses consisting of several outliers and extremes in the 129 data sets left over.

Checking for bias data sets was performed through the use of the boxplot option from SPSS® 9.05 for Windows™. As previously described, the boxplot graphically displays a summary of information about the distribution of values including median, quartiles, outliers, and extremes. Referring to variables used in this study, a total of 48 boxplots were generated for 16 field disruptions with 3 conditions each. An example of identifying outliers and extremes from the data set using boxplots for congestion is illustrated in Figure 4.8. Outliers are denoted with a small circle, whereas extremes are designated with an asterisk mark. The code next to each outlier or extreme identifies the respondent. The three boxplots shown in the figure refer to the summary of loss of productivity of minor, moderate, and severe congestions, respectively. For severe congestion, this figure has depicted that there is largely a positively skewed distribution, and the outliers and extremes at the positive tail of the distribution have significantly increased the value of the mean. This example highlights the need of criteria for eliminating a data set from the analysis.

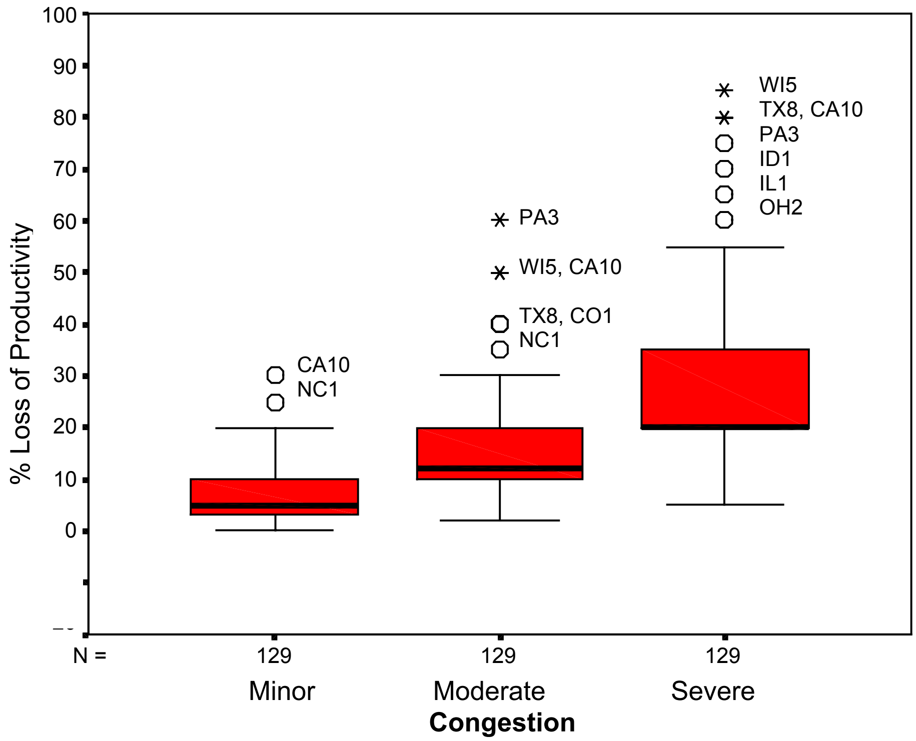


Figure 4.8 Boxplots Displaying Outliers and Extremes for Three Congestion Factors

Once all the boxplots were generated and all outliers and extremes were identified, a frequency score (F.Score) was employed as criteria to determine which data sets should be discarded (Cho, 2000). A frequency score for each field condition of each disruption was then computed using Equation 3.1, as shown below.

Frequency Score = 3 x No. of Extremes + 1 x No. of Outliers

Frequency scores for the data sets were calculated, some of which are displayed in Table 4.5. SC1 designates the first respondent from South Carolina, with

12 extremes and 10 outliers in this data set resulting in a frequency score of 46. The first cut in the screening process was conducted on data sets with a frequency score of 10 or higher. Therefore, the first 13 data sets were removed from further analysis because they significantly skewed the means. From 129 original data sets, there was a total of 116 data sets after the first cut.

Table 4.5 Part of the Frequency Score Calculation Results

	SC1	PA3	CA10	HI1	CO1	WI5	TX8	AL1	NV1	ID1
Extremes	12	8	8	9	4	4	2	3	2	2
Outliers	10	13	7	1	12	8	13	7	9	8
F.Score	46	37	31	28	24	20	19	16	15	14
	PA5	**OH2**	**TX12**	**IL1**	**TX3**	**MO3**	**OH4**	**CA12**	**TX9**	**TX5**
Extremes	4	1	0	0	2	2	2	1	1	0
Outliers	2	10	13	9	3	2	2	4	4	6
F.Score	14	13	13	9	9	8	8	7	7	6
	VA4	**VA1**	**IL9**	**OR1**	**PA4**	**TN2**	**TX11**	**WI14**	**NC1**	**VA5**
Extremes	1	0	1	1	0	0	0	0	0	0
Outliers	3	5	1	1	4	4	4	4	3	3
F.Score	6	5	4	4	4	4	4	4	3	3
	AZ1	**IL7**	**KY1**	**MO2**	**TX6**	**CA1**	**CA9**	**CO2**	**CO3**	**CO4**
Extremes	0	0	0	0	0	0	0	0	0	0
Outliers	2	2	2	2	2	1	1	1	1	1
F.Score	2	2	2	2	2	1	1	1	1	1
		VT1	**WA1**	**WA2**	**WA3**	**WI1**	**WI3**	**WI6**	**WV1**	**WY1**
Extremes	…	0	0	0	0	0	0	0	0	0
Outliers	…	0	0	0	0	0	0	0	0	0
F.Score	…	0	0	0	0	0	0	0	0	0

After eliminating the 13 data sets due to their high frequency score, the researcher again inspected for outliers and extremes using the boxplot option and computing frequency scores with the remaining 116 data sets. Another 48 boxplots were generated and 116 frequency scores were calculated. Even though the first trial of the boxplot analysis greatly reduced the variances in means of productivity loss, the second trial of the analysis uncovered that there were some data sets which skewed the distribution and caused high variances in the means. Nevertheless, the researcher felt that removing additional data sets would not significantly increase the accuracy of the means of productivity loss. Additionally, the model being developed was initially intended to serve as a reference, and modifications should be made according to the particular company, crew and job. More importantly, it was likely that these identified outliers and extremes would be detected and discarded in the next step of the data screening process. As a result, approximately 76% of the total questionnaires were returned. The remaining 116 data sets as shown in Table 4.6 were used for the next data screening process of determining outliers and extremes.

Table 4.6 Summary of Valid Data Sets by State

State	**AL**	**AR**	**AZ**	**CA**	**CO**	**CT**	**DE**	**FL**	**GA**	**HI**
No. of Participants	0	0	2	10	3	1	0	2	1	0
State	**IA**	**ID**	**IL**	**IN**	**KS**	**KY**	**LA**	**MA**	**MD**	**ME**
No. of Participants	0	0	12	5	0	2	0	2	5	1
State	**MI**	**MN**	**MO**	**MS**	**MT**	**NC**	**ND**	**NE**	**NH**	**NJ**
No. of Participants	4	2	5	0	1	2	1	0	1	1
State	**NM**	**NV**	**NY**	**OH**	**OK**	**OR**	**PA**	**SC**	**SD**	**TN**
No. of Participants	0	0	5	8	0	3	3	2	0	3
State	**TX**	**UT**	**VA**	**VT**	**WA**	**WI**	**WV**	**WY**		
No. of Participants	10	1	7	1	3	5	1	1		

The study proceeded with checking for outliers and extremes through the use of the boxplot option from SPSS® 9.05 for Windows™. Out of the 116 data points for each standard condition of field disruptions, many outliers and extremes were identified and removed from the database prior to further analysis. Table 4.7 summarizes the data points for each field factor. For instance, for minor congestion, four outliers and extremes were identified and removed, leaving a total of 112 data points in the database.

Table 4.7 Number of Data Points Remaining After the Data Screening Process

No.	**Field Disruptions**	**Number of Data Points Used for Standard Field Conditions**		
		Minor	**Moderate**	**Severe**
1	Congestion	112	110	114
2	Morale and Attitude	94	113	112
3	Labor Reassignment	112	113	113
4	Crew Size Change	115	110	113
5	Added Operations	95	112	108
6	Diverted Supervision	115	114	112
7	Learning Curve	98	114	110
8	Errors and Omissions	97	114	110
9	Beneficial Occupancy	116	115	114
10	Joint Occupancy	116	116	114
11	Site Access	111	112	116
12	Logistics	108	111	116
13	Fatigue	112	111	114
14	Work Sequence	116	116	113
15	Overtime	115	115	114
16	Weather or Environment	116	111	113

4.6 Summary

This chapter addressed major steps in the development of the research survey, as well as the data screening process. The 16 field disruptions and standard conditions were first developed based on the comprehensive literature review and the brainstorming discussions with research participants. The complete set of survey documents, including the questionnaire, standard field conditions, example of the questionnaire response, and computation sample, was then compiled and distributed to 950 members of MCAA throughout the U.S. The descriptive analysis was conducted based on the total of 152 questionnaires returned. The data screening process was then conducted to identify invalid data sets, biased responses, and outliers and extremes. This process finally resulted in a total of 116 valid data points or less for each standard condition of field disruptions. These data points were available for further analysis, as presented in the next chapter.

CHAPTER V

RESEARCH FINDINGS AND DISCUSSION

In recent years, there has been considerable debate over the calculation of damages due to productivity loss. A number of research studies have presented several estimates of productivity loss due to a variety of factors, some of which are related to this research study and represented in this chapter. This chapter primarily focuses on results and discussion of findings based on this research study as well as prior studies. Even though the sources of these studies are not directly related, a range of estimates can be considered for comparison. Further analysis of other studies is beyond the scope of this study. The research results and the comparison allow estimators to generate a more defined and accurate estimate. Each section of this chapter includes an overview of each productivity factor and results of other studies regarding evaluations of productivity loss, followed by the findings from this research study.

5.1 Congestion

An extensive literature review shows that congestion typically causes productivity loss in construction. Congestion is similar or the same as other terminologies such as overcrowding, stacking of trades, and overmanning. These terms refer to circumstances that cause physically limited spaces due to other trades working concurrently in the same area, resulting in increased difficulty in achieving efficient work performance. For instance, interior brick veneer work might be interrupted by other trades' work including suspended ceiling installation and flooring work, which can initiate congestion. The Modification Impact Evaluation Guide of the U.S. Army Corps of Engineers (1979) (hereafter referred to as "CORPS") states that congestion is one of many problems commonly caused by schedule acceleration, requiring a contractor to accomplish a fixed amount of work within a shorter time frame or to achieve more work within a fixed time frame. It frequently prohibits use of optimum crew size, causes inability to locate tools and materials conveniently and initiates presence of additional safety hazards, ultimately causing loss of productivity. The optimum crew size can be retrieved from a company's database or well-known industry sources. For instance, Means (2000) suggests that a crew of three bricklayers and two bricklayer helpers can lay 1,500 brick per day for four inch standard brick veneer.

Several other studies provide quantitative adjustments to incorporate this effect on productivity in cost estimates. MCA (1976) presents estimates of loss of productivity due to several adverse factors that are beyond the control of mechanical contractors, including staking of trades. It indicates that productivity loss for minor, average, and severe situations are 10%, 20%, and 30%, respectively. The sources of the results, however, are not known and the three situations are not clearly identified. Neil and Knack (1984) have also proposed adjustment factors to quantify the effect of the factor, referred to as crew work space. In this paper, “fixed factors” originally presented by Edmonson (1974) were represented to quantify productivity loss. These “fixed factors” indicate relative productivity for several locations in the U.S. Based on the “fixed factors” for Houston, Texas, the adjustment factors result in a loss of productivity of 15% and 30% for conditions where one-half and one-third space distances are available for a crew to work, respectively. However, Neil and Knack (1984) provide little insight on database characteristics, data collection procedures, or validation processes.

This research investigation mainly focuses on quantification of productivity loss due to congestion whereas three different degrees of field conditions exist. Table 5.1 presents the description of standard field conditions for congestion. Research findings for congestion are graphically presented in Table 5.2 and Figure 5.1. These research results show that, for minor congestion, an average productivity loss of five percent exists when a masonry crew works in the same area with an additional crew or contractor one day a week. Loss of productivity has increased about two-fold when additional crews work in the same area two or three days per week. Once additional crews begin working in the same area everyday, loss of productivity increases up to approximately 24%. These outcomes have been proven to be low based on other research studies, as shown in Table 5.3, whereas estimates from Contractor's Consultants Corporation (CCC) (1984) are the highest of all. Results from CCC (1984) presented in this section and hereafter are based on a recent paper published by Heather and Summers (1996). In this study, the results also show that masonry contactors have experienced a great difference in estimates ranging from 5 to 50% when the severe condition exists.

Table 5.1 Description of Standard Field Conditions for Congestion

Minor	Moderate	Severe
An additional crew/contractor working in the same area 1 day/week	Additional crews/contractors working in the same area 2-3 days/week	Additional crews/contractors working in the same area everyday

Table 5.2 Percentage of Productivity Loss for Congestion

Congestion	Field Conditions		
	Minor	Moderate	Severe
Mean	5	12	24
Median	5	10	20
Mode	5	10	20
Low	0	2	5
High	10	25	50
Range	10	23	45
Standard Deviation	2.9	5.8	11.9

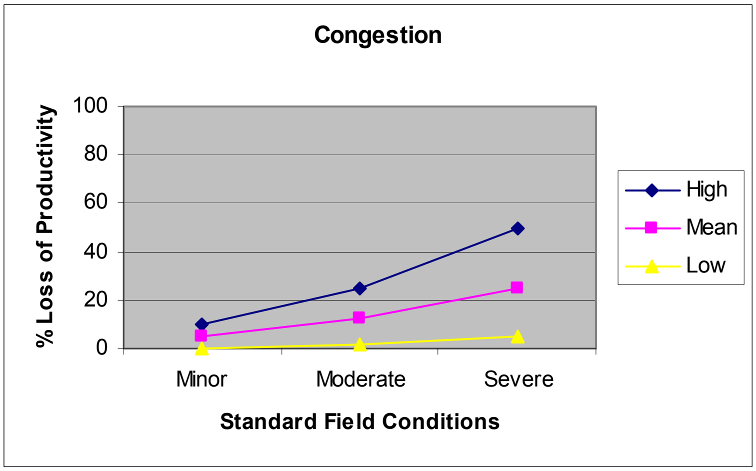


Figure 5.1 Loss of Productivity Due to Congestion

Table 5.3 Comparison Table of Loss of Productivity Due to Congestion

Congestion	Field Conditions		
	Minor	**Moderate**	**Severe**
Research Results	5%	12%	24%
CCC[I] (1984)	15%	33%	50%
CORPS[II] (1979)	N/A	17%	N/A
MCA[III] (1976)	10%	20%	30%
Neil and Knack (1984)	N/A	15%	30%

[I] CCC – Contractor's Consultants Corporation
[II] CORPS – the U.S. Army Corps of Engineers
[III] MCA – Mechanical Contractors Association of America

5.2 Morale and Attitude

Numerous research studies have found that factors related to morale and attitude can contribute to significant loss of productivity. This factor refers to changes involving excessive inspections, multiple change orders and rework, schedule disruptions, or poor site conditions. Such situations can negatively influence masonry crews of ongoing work, resulting in productivity loss. Numerous factors interact with morale, so it is a challenge to quantify this factor (Borcherding and Alarcon, 1991). The Modification Impact Evaluation Guide of the CORPS (1979) does not consider morale as a productivity factor because it significantly depends on labor relations responsibilities. However, MCA (1976) does provide estimates for productivity loss due to this effect. This paper suggests a 5%, 15%, and 30% loss for minor, average, and severe conditions, while having no further clarification of the conditions.

In this research study, however, the estimates as shown in Table 5.5 and 5.6 are relatively lower than those of MCA (1976). The estimated loss of productivity is four percent where less than three inspections or disruptions occurred per week, lasting an average of one hour each. However, as depicted in Figure 5.2, while involving daily 1- to 2-hour inspections or moderate conditions, a masonry crew can experience a loss of productivity of 12%. The loss of productivity increases to 21% when severe conditions are present involving full-time inspection. This factor has a great impact on productivity with a wide range of estimated loss of productivity. This is probably a result of a number of overlapping influences on morale and attitude. Table 5.4 presents the description of standard field conditions for morale and attitude.

Table 5.4 Description of Standard Field Conditions for Morale and Attitude

Minor	Moderate	Severe
Less than 3 inspections/week, average 1 hour each	Daily inspection, 1-2 hours each	Full time inspection

Table 5.5 Percentage of Productivity Loss for Morale and Attitude

Morale and Attitude	Field Conditions		
	Minor	Moderate	Severe
Mean	4	12	21
Median	5	10	20
Mode	5	10	20
Low	0	0	0
High	9	30	55
Range	9	30	55
Standard Deviation	2.0	7.4	11.9

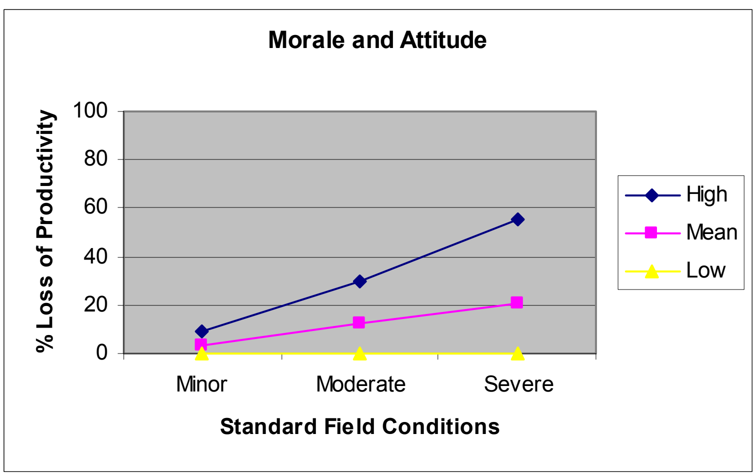


Figure 5.2 Loss of Productivity Due to Morale and Attitude

Table 5.6 Comparison Table of Loss of Productivity Due to Morale and Attitude

Morale and Attitude	Field Conditions		
	Minor	Moderate	Severe
Research Results	4%	12%	21%
MCA[1] (1976)	5%	15%	30%

[1] MCA – Mechanical Contractors Association of America

5.3 Labor Reassignment

Another significant productivity factor in this category is labor reassignment. This involves rescheduling the masonry crews or expediting the masonry work without necessary preparation, which results in lost time due to the move-in and move-out of masonry crews. According to Means (2000), a crew of three bricklayers and two bricklayer helpers have a daily production rate of 395 concrete blocks for inner walls, so if work must be expedited requiring more bricklayers and bricklayer helpers, the move-in of the needed crews can interrupt the on-going work and result in a lower production rate. This factor is commonly due to unexpected or excessive changes, or rescheduled completion of certain work phases. The problems partially result from a period of orientation to new work, and the loss is repeated if workers are returned to their original work (Borcherding and Alarcon, 1991). MCA (1976) has shown percentages of productivity loss due to this factor; minor, average, and severe situations can result in a productivity loss of 5%, 10%, and 15%, respectively.

This research study resulted in different estimates of productivity loss due to labor reassignment, as shown in Table 5.9. Table 5.7 presents the description of standard field conditions for labor reassignment. The findings presented in Table 5.8 and Figure 5.3 show that if masonry workers move between job areas only once a week, they will suffer an average productivity loss of five percent. This loss dramatically increases to 12% once the workers need to move between job areas two to three times per week. For severe field conditions, the workers are required to move between job areas more than three times per week, which results in an average productivity loss of 21%.

Table 5.7 Description of Standard Field Conditions for Labor Reassignment

Minor	Moderate	Severe
Crews move once a week between job areas	Crews move 2-3 times/week between job areas	Crews move almost daily between jobs

Table 5.8 Percentage of Productivity Loss for Labor Reassignment

Labor Reassignment	Field Conditions		
	Minor	Moderate	Severe
Mean	5	12	21
Median	5	10	20
Mode	5	10	20
Low	0	2	2
High	15	30	50
Range	15	28	48
Standard Deviation	3.1	6.4	11.4

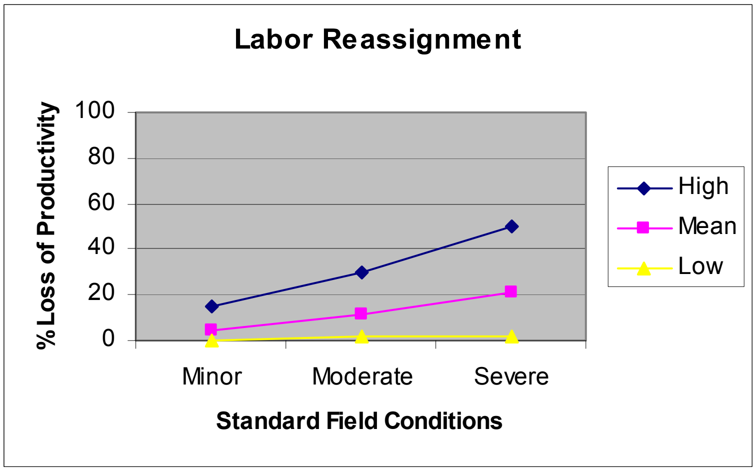


Figure 5.3 Loss of Productivity Due to Labor Reassignment

Table 5.9 Comparison Table of Loss of Productivity Due to Labor Reassignment

Labor Reassignment	Field Conditions		
	Minor	Moderate	Severe
Research Results	5%	12%	21%
CCC[I] (1984)	10%	20%	30%
MCA[II] (1976)	5%	10%	15%

[I] CCC – Contractor's Consultants Corporation
[II] MCA – Mechanical Contractors Association of America

5.4 Crew Size Change

There have been several attempts to highlight factors associated with resources and site management including crew size change or unbalanced crews. Crew size change refers to changes that increase or decrease the optimum crew size, resulting in inefficiency or workflow disruption. To determine the total cost of brick installation, for example, Means (2000) specifies a crew of three bricklayers and two bricklayer helpers with a daily output of approximately 1,800 common bricks for eight inch solid walls. If a change order occurs with a short notice, resulting in a shortage of one bricklayer, the crew will have a lower daily output and therefore require a longer installation time. As stated in many studies, increasing the crew size generally results in decreased productivity due to altering labor rhythm and breaking up the original team effort (MCA, 1976; the Army Corps of Engineers, 1979; Borcherding and Alarcon, 1991). Furthermore, impairment can occur due to limited working space, diluted supervision, and lack of management support (MCA, 1976; Borcherding and Alarcon, 1991). MCA (1976) refers to this factor as crew size efficiency, and provides estimates of loss due to the effect of this factor. Minor, moderate, and severe conditions of this factor typically generate productivity loss of 10%, 20%, and 30%, respectively. This paper, as stated earlier, provides very little insight on database characteristics and data collection procedures.

This research study resulted in lower outcomes in estimates of productivity loss. Table 5.10 presents the description of standard field conditions for crew size change. Table 5.11 and Figure 5.4 show the research findings, and Table 5.12 presents a comparison of results from three studies. This research investigation shows that there is a five percent productivity loss when crew size change exists once per week. When the change increases its frequency to two to three times per week, estimated loss of productivity has increased up to 11%. This rise increases to a 20% productivity loss, when crew size change takes place almost daily. Even though these mean averages are almost twice as low as other estimates, the means result from a wide range of the estimates found in the study. This means that the crew size change has a great range of impact on productivity and detailed investigations should be conducted if severe conditions exist.

Table 5.10 Description of Standard Field Conditions for Crew Size Change

Minor	Moderate	Severe
Crew size changes once/week	Crew size changes 2-3 times/week	Crew size changes almost daily

Table 5.11 Percentage of Productivity Loss for Crew Size Change

Crew Size Change	Field Conditions		
	Minor	Moderate	Severe
Mean	5	11	20
Median	5	10	20
Mode	5	10	20
Low	0	3	5
High	15	25	50
Range	15	22	45
Standard Deviation	3.6	5.3	10.7

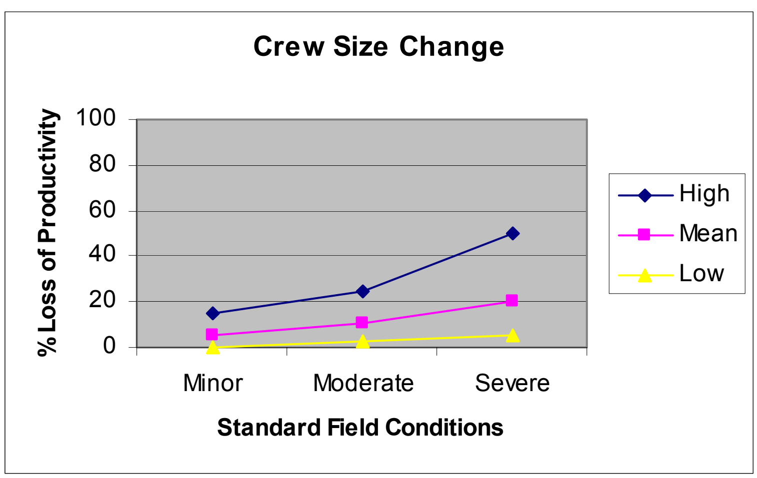


Figure 5.4 Loss of Productivity Due to Crew Size Change

Table 5.12 Comparison Table of Loss of Productivity Due to Crew Size Change

Crew Size Change	Field Conditions		
	Minor	Moderate	Severe
Research Results	5%	11%	20%
CCC[I] (1984)	10%	30%	50%
MCA[II] (1976)	10%	20%	30%

[I] CCC – Contractor's Consultants Corporation
[II] MCA – Mechanical Contractors Association of America

5.5 Added Operations

Added operations or concurrent operations are of interest to many researchers in the construction field. This factor includes any changed conditions that initiate operations additional to ongoing masonry operations, which take place in a physically limited space. The productivity loss usually results from stacking of the masonry contractor's own force working on an already planned sequence of operations. This factor commonly exists when there is a need to accomplish additional work during schedule acceleration. Estimates of productivity loss due to this factor are presented by MCA (1976). Productivity losses of 5%, 15%, and 25% are suggested to determine the effect if the conditions are minor, average, and severe, respectively.

This research study reveals similar results to those of MCA (1976), as shown in Table 5.15. Additional findings are presented in Table 5.14 and Figure 5.5. An average productivity loss of four percent is present when minor conditions exist or there are additional operations once a week. When additional operations disrupt a masonry crew two to three times a week, the estimated loss of productivity increases to 11%. The severe condition involving additional operations more than three times a week yields an average productivity loss of 18%. Table 5.13 presents the description of standard field conditions for added operations.

Table 5.13 Description of Standard Field Conditions for Added Operations

Minor	Moderate	Severe
Work disrupted once/week	Work disrupted 2-3 times/week	Work disrupted almost daily

Table 5.14 Percentage of Productivity Loss for Added Operations

Added Operations	Field Conditions		
	Minor	Moderate	Severe
Mean	4	11	18
Median	5	10	16
Mode	5	10	20
Low	0	2	4
High	10	25	40
Range	10	23	36
Standard Deviation	1.9	5.4	8.3

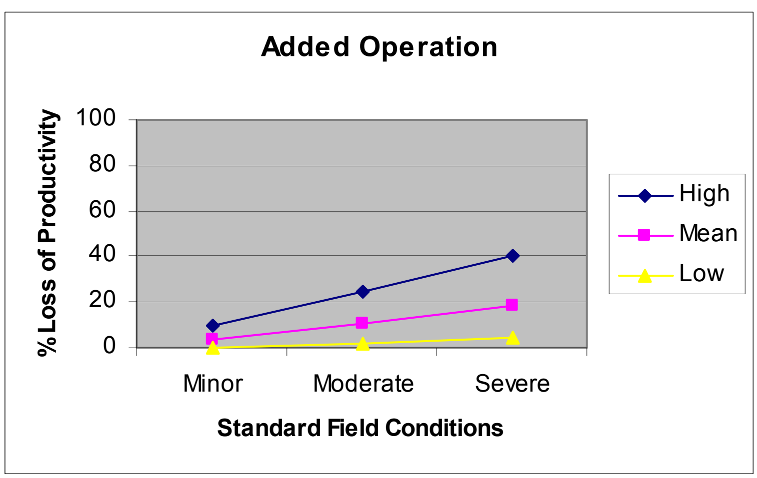


Figure 5.5 Loss of Productivity Due to Added Operations

Table 5.15 Comparison Table of Loss of Productivity Due to Added Operations

Added Operations	Field Conditions		
	Minor	Moderate	Severe
Research Results	4%	11%	18%
MCA[1] (1976)	5%	15%	25%

[1] MCA – Mechanical Contractors Association of America

5.6 Diverted Supervision

Findings from numerous research studies have highlighted productivity factors related to management characteristics. A major factor associated with management characteristics is diverted supervision or dilution of supervision. This factor addresses changes that cause distraction of supervision from multiple on-going activities, in order to analyze and plan changed work, stop and replan ongoing work or reschedule work. Diverted supervision is critical when the masonry work is accelerated or changed and a significant amount of instruction is required. MCA (1976) estimates loss of productivity as 10%, 15%, and 25% for minor, average, and severe situations.

This research investigation found that the results from this study are somewhat lower than that of MCA (1976), as shown in Table 5.18. An average productivity loss of six percent when diverted supervision occurs twice a week for only two hours or less each as shown in Table 5.17 and Figure 5.6. An average productivity loss of 13% arises where diverted supervision occurs two hours or less daily. The loss increases to an average productivity loss of 22% when diverted supervision exists daily for more than three hours. This factor has a broad range of impacts for all conditions, likely depending upon the degree of management involved in the masonry work at a certain period of time. For instance, in the morning, a masonry crew needs advice or instructions for their work, requiring concentrated attention from management at that time. This circumstance can generate high loss of productivity. Table 5.16 presents the description of standard field conditions for diverted supervision.

Table 5.16 Description of Standard Field Conditions for Diverted Supervision

Minor	Moderate	Severe
2 times/week, 1-2 hours	Daily, 1-2 hours	Daily, 4 hours or more

Table 5.17 Percentage of Productivity Loss for Diverted Supervision

Diverted Supervision	Field Conditions		
	Minor	Moderate	Severe
Mean	6	13	22
Median	5	10	20
Mode	5	10	15
Low	0	2	5
High	15	30	55
Range	15	28	50
Standard Deviation	3.4	7.1	12.9

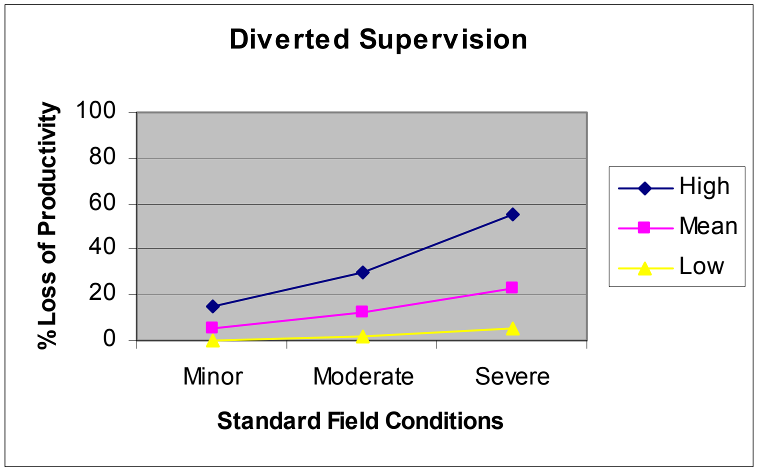


Figure 5.6 Loss of Productivity Due to Diverted Supervision

Table 5.18 Comparison Table of Loss of Productivity Due to Diverted Supervision

Diverted Supervision	**Field Conditions**		
	Minor	**Moderate**	**Severe**
Research Results	6%	13%	22%
MCA[1] (1976)	10%	15%	25%

[1] MCA – Mechanical Contractors Association of America

5.7 Learning Curve

Researchers have shown an increasing interest in the learning curve as an influence on productivity. The learning curve refers to a period of orientation necessary to become familiar with new tasks or changed conditions, and increased productivity is expected as the individual becomes more skilled and familiar with the assigned tasks, tool locations, and work procedures (Borcherding and Alarcon, 1991). For masonry construction, the production rate usually decreases while an individual is obtaining more skills or becoming familiar with masonry work procedures, tool locations and environment. This factor therefore refers to changes that cause masonry workers to lose time while becoming familiar with and adjusting to new work or a new environment.

Many publications have presented the effects of the learning curve. The earliest published research on learning curve originated in the aircraft manufacturing industry. In the industrial sector, Wright introduced the concept of learning curve for production productivity. This rule is called Wright's 80% rule and states that the accumulated mean of operational times will be reduced to 80% of the expected value computed based on the original mean, when doubling the number of identical operations (Schwartzkopf, 1995). The equivalent of Wright's 80% rule was later found to be 87% to 93% in building operations of a repetitive nature (United Nations Committee and Housing, 1965). More recent paper regarding learning curve was published by MCA (1976). It presents quantitative evaluations to determine loss of productivity due to this factor. The investigation determined losses of productivity of 5%, 15%, and 30% for minor, average, and severe conditions, respectively.

Findings from this research study have revealed different results compared to other studies as shown in Table 5.21. Results from this study are summarized in Table 5.20 and Figure 5.7. Table 5.19 presents the description of standard field conditions for learning curve. Minor conditions representing change from one masonry operation to another operation once a week yield an average productivity loss of four percent. Moderate conditions exist with changes two to three times per week, which has an average productivity loss of 11%. Severe conditions, in contrast, indicate changes more than three times per week, which cause a high average productivity loss of 18%.

Table 5.19 Description of Standard Field Conditions for Learning Curve

Minor	Moderate	Severe
Once a week	2-3 times/week	Daily

Table 5.20 Percentage of Productivity Loss for Learning Curve

Learning Curve	Field Conditions		
	Minor	Moderate	Severe
Mean	4	11	18
Median	5	10	15
Mode	5	10	15
Low	0	2	4
High	9	25	50
Range	9	23	46
Standard Deviation	2.0	6.1	10.1

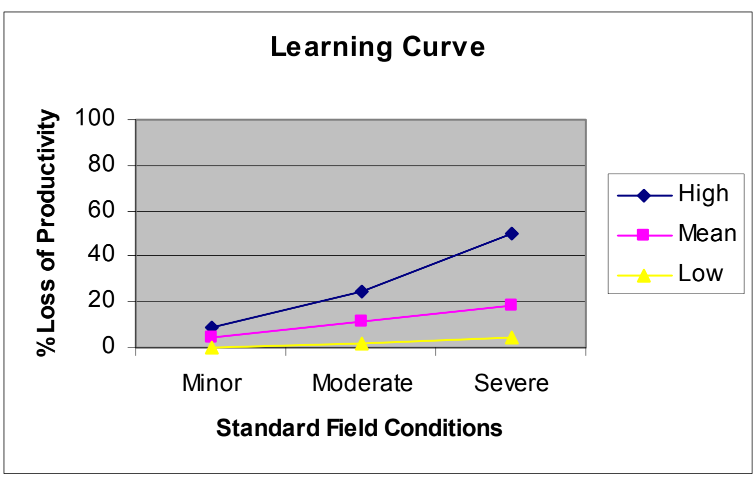


Figure 5.7 Loss of Productivity Due to Learning Curve

Table 5.21 Comparison Table of Loss of Productivity Due to Learning Curve

Learning Curve	Field Conditions		
	Minor	Moderate	Severe
Research Results	4%	11%	18%
CCC[I] (1984)	10%	23%	35%
MCA[II] (1976)	5%	15%	30%

[I] CCC – Contractor's Consultants Corporation
[II] MCA – Mechanical Contractors Association of America

5.8 Errors and Omissions

In recent years, construction researchers and practitioners have begun to account for engineering errors and omissions. This factor represents changed conditions involving mistakes or unclear instructions in drawings, technical documents or supervisions; which cause lost time, out-of-sequence work, rework or other work conflicts. Engineering errors and omissions can be both the cause and effect of changes and commonly result in loss of productivity (Borcherding and Alarcon, 1991). From the results presented in MCA (1976), it is evident that errors and omissions cause productivity losses of one percent, three percent, and six percent for minor, average, and severe situations, respectively.

From the evidence presented in this report, it is likely that errors and omissions cause loss of productivity as much as and even more than four times higher than the losses reported by MCA (1976), as shown in Table 5.24. Based upon studies of impacted projects (Borcherding and Alarcon, 1991), the higher loss percentages due to design constraints support the findings in this study rather than MCS's very low percentages. Table 5.22 presents the description of standard field conditions for errors and omissions. Table 5.23 and Figure 5.8 present a summary of the research investigations. It was found that errors and omissions taking place every two weeks or more are considered minor and generate an average productivity loss of four percent. Meanwhile, changed conditions every week or every one to two days are classified as moderate and severe, respectively, and they produce an average productivity loss of 11% and 19%, respectively.

Table 5.22 Description of Standard Field Conditions for Errors and Omissions

Minor	Moderate	Severe
Every 2 weeks or more	Every week	Every 1 or 2 day(s)

Table 5.23 Percentage of Productivity Loss for Errors and Omissions

Errors and Omissions	Field Conditions		
	Minor	Moderate	Severe
Mean	4	11	19
Median	5	10	15
Mode	5	10	15
Low	0	2	4
High	8	25	45
Range	8	23	41
Standard Deviation	1.9	5.8	9.6

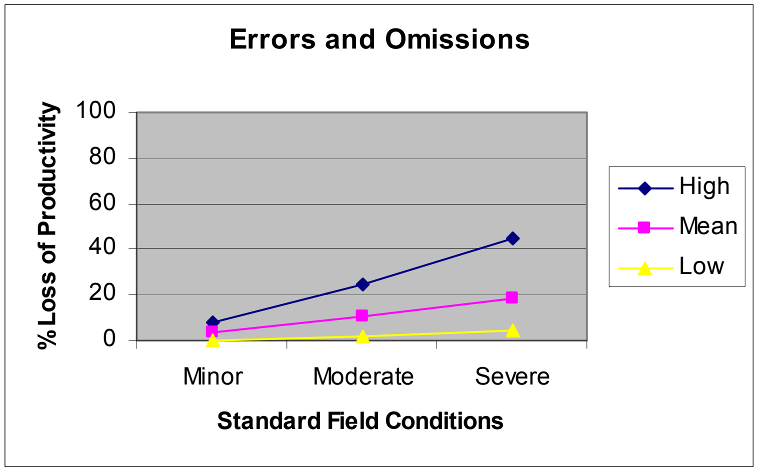


Figure 5.8 Loss of Productivity Due to Errors and Omissions

Table 5.24 Comparison Table of Loss of Productivity Due to Errors and Omissions

Errors and Omissions	Field Conditions		
	Minor	Moderate	Severe
Research Results	4%	11%	19%
MCA[1] (1976)	1%	3%	6%

[1] MCA – Mechanical Contractors Association of America

5.9 Beneficial Occupancy

One of the major field factors facing masonry contractors today is beneficial occupancy. This factor focuses on changes that require the use of premises by the owner prior to masonry work completion, restricted work access, or working close to the owner's personnel or equipment. The effect of this factor has been quantified by MCA (1976). The estimated productivity losses of this factor are 15%, 25%, and 40% for minor, moderate, and severe conditions, respectively. These results are some of the highest values among all factors presented in MCA (1976). This distinction highlights the significant effect of this factor on labor productivity of mechanical construction.

This research study has verified that beneficial occupancy does in deed have a major impact on productivity in masonry construction. Table 5.25 presents the description of standard field conditions for beneficial occupancy. Tables 5.26 and 5.27, and Figure 5.9 show analysis results of this study as well as a comparison between results of this study and those of MCA (1976). Although the results from this study are relatively lower than those of MCA (1976), they are higher than many other factors in this research study. Findings from this study indicate that an average productivity loss of seven percent exists when there is punch list work or minor conditions. Beneficial occupancy can be considered as moderate when there is a punch list and new work one week prior to the original completion date, causing an average productivity loss of 14%. Severe conditions, however, involving numerous crews and overtimes only a few days prior to the original completion date can generate an average productivity loss of 25%.

Table 5.25 Description of Standard Field Conditions for Beneficial Occupancy

Minor	**Moderate**	**Severe**
Punch list work	Punch list and new work one week prior to the original completion date	Many crews and overtime a few days prior to the original completion date

Table 5.26 Percentage of Productivity Loss for Beneficial Occupancy

Beneficial Occupancy	**Field Conditions**		
	Minor	**Moderate**	**Severe**
Mean	7	14	25
Median	5	10	20
Mode	10	10	15
Low	0	0	1
High	20	40	63
Range	20	40	62
Standard Deviation	5.5	8.9	14.1

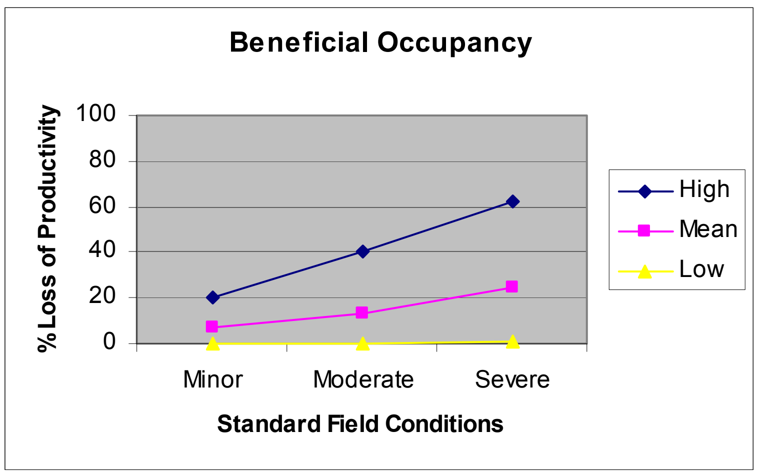


Figure 5.9 Loss of Productivity Due to Beneficial Occupancy

Table 5.27 Comparison Table of Loss of Productivity Due to Beneficial Occupancy

Beneficial Occupancy	**Field Conditions**		
	Minor	**Moderate**	**Severe**
Research Results	7%	14%	25%
MCA[1] (1976)	15%	25%	40%

[1] MCA – Mechanical Contractors Association of America

5.10 Joint Occupancy

Another factor currently of interest to masonry contractors is joint occupancy. This factor deals with significant changes that require masonry work to be done while other trades occupy the same area. In such a busy work area, for example, productivity loss can result from loss of masonry tools or difficulty in locating brick stacks. MCA (1976) has quantified loss of productivity due to this factor for mechanical work. It shows that 5%, 12%, and 20% of productivity losses may exist for minor, average, and severe conditions, respectively.

Compared to MCA (1976), results from this research study indicate higher losses of productivity due to joint occupancy, as shown in Figure 5.10 and Tables 5.29 and 5.30. An average productivity loss of seven percent exists when a facility is partly occupied and only one additional trade is working in the same area with the masonry crew. The average loss increases up to 14% when a facility is partly occupied and two or three trades are working in the same area. Even more severely, there is an average productivity loss of 25% when a facility is fully in operation and masonry work is on limited shifts. Table 5.28 presents the description of standard field conditions for joint occupancy.

Table 5.28 Description of Standard Field Conditions for Joint Occupancy

Minor	**Moderate**	**Severe**
Facility partly occupied, one trade working	Facility partly occupied, 2-3 trades working in the same area	Facility in operation, work on limited shifts

Table 5.29 Percentage of Productivity Loss for Joint Occupancy

Joint Occupancy	**Field Conditions**		
	Minor	**Moderate**	**Severe**
Mean	7	14	25
Median	5	15	25
Mode	10	15	20
Low	0	0	4
High	20	35	50
Range	20	35	46
Standard Deviation	4.4	7.1	11.3

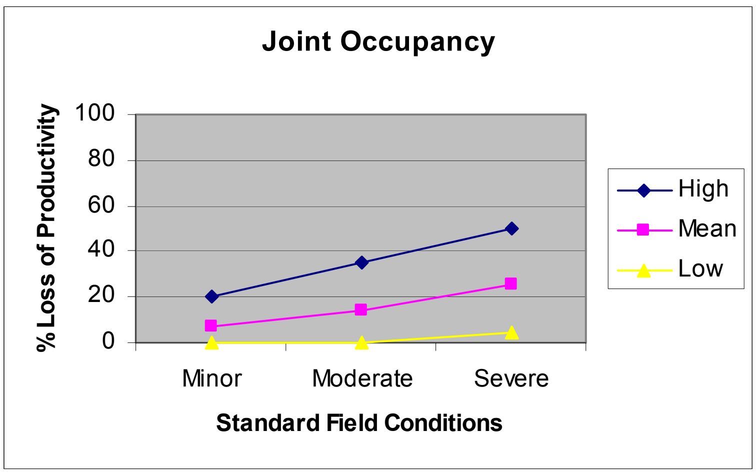


Figure 5.10 Loss of Productivity Due to Joint Occupancy

Table 5.30 Comparison Table of Loss of Productivity Due to Joint Occupancy

Joint Occupancy	**Field Conditions**		
	Minor	**Moderate**	**Severe**
Research Results	7%	14%	25%
MCA[1] (1976)	5%	12%	20%

[1] MCA – Mechanical Contractors Association of America

5.11 Site Access

There have been several attempts to highlight factors associated with resources and site management, one of which is site access. This factor deals with changes involving inconvenient access to masonry work areas, inadequate or congested work spaces or remote materials storage. Productivity loss usually occurs when additional work-hours are needed to demolish an existing physical structure, or additional time is required to access a work area or materials storage for any reason (Borcherding and Alarcon, 1991). MCA (1976) has presented estimates of the effect of this factor. Findings from this investigation state that productivity losses due to this factor are 5%, 12%, and 30% for minor, average, and severe conditions, respectively.

The analysis of this research study, however, indicates that minor conditions, involving convenient access to a work area four days per week or more or a distance of less than 25 yards to materials storage, have an average productivity loss of seven percent, as shown in Table 5.32 and Figure 5.11. This result shows the highest impact among minor conditions compared with other studies, as shown in Table 5.33. Moderate conditions involving convenient access to a work area two to three times per week or a distance of 25 to 50 yards to materials storage, yield an average productivity loss of 14% Additionally, when a masonry crew has extremely limited access to a work area or a distance of more than 50 yards to material storage, the analysis result indicates an average productivity loss of 27%. This factor signifies a considerable impact to masonry productivity compared to other factors, and it is essential that masonry practitioners be aware of any situations that can cause this factor. Table 5.31 presents the description of standard field conditions for site access.

Table 5.31 Description of Standard Field Conditions for Site Access

Minor	Moderate	Severe
4 days/week, < 25 yards to materials storage	2-3 days/week, 25-50 yards to materials storage	Once/week, > 50 yards to materials storage

Table 5.32 Percentage of Productivity Loss for Site Access

Site Access	Field Conditions		
	Minor	Moderate	Severe
Mean	7	14	27
Median	5	15	25
Mode	5	10	20
Low	0	0	0
High	15	30	60
Range	15	30	60
Standard Deviation	4.3	7.2	13.0

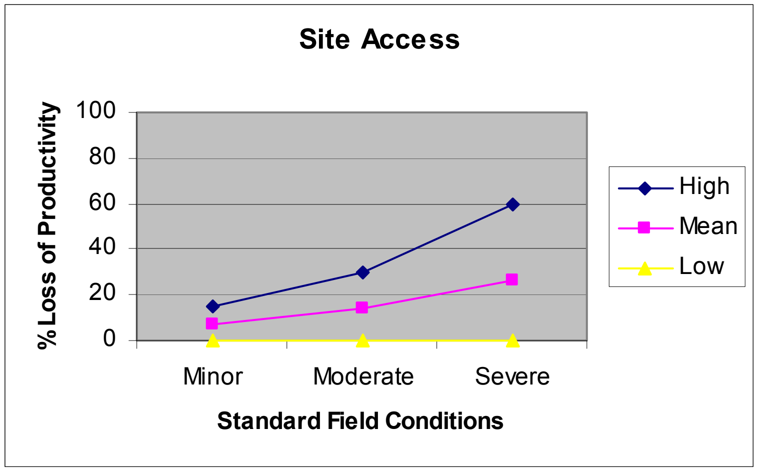


Figure 5.11 Loss of Productivity Due to Site Access

Table 5.33 Comparison Table of Loss of Productivity Due to Site Access

Site Access	Field Conditions		
	Minor	Moderate	Severe
Research Results	7%	14%	27%
CCC[I] (1984)	5%	28%	50%
MCA[II] (1976)	5%	12%	30%

[I] CCC – Contractor's Consultants Corporation
[II] MCA – Mechanical Contractors Association of America

5.12 Logistics

Numerous investigations have presented several negative factors associated with materials and tools availability or logistics. This factor involves changes that cause an unsatisfactory supply of masonry materials by the owner or general contractor, inability to control procurement, delivery or re-handling of substituted materials, or difficulty controlling materials flow to work areas. It is conceivable that materials and tools must be available for craftsmen to perform their work; otherwise, loss of productivity can occur due to idle time or ineffective work. As logical problems develop, consequential difficulties arise, including hoarding in-short-supply items, and resequencing planned work to make use of available materials and tools may arise (Borcherding and Alarcon, 1991). These obstacles and other problems related to materials flow or materials procurement and delivery can cause loss of productivity. Findings from several investigations have confirmed this fact.

MCA (1976) has proposed percentages of productivity loss due to logistics. Losses of productivity are estimated to be as high as 10%, 25%, and 50% if the conditions are minor, average, and severe, respectively. These high values show that logistics is probably the most significant and extreme factor in construction. A more recent research study conducted by Neil and Knack (1984) have quantified effects of this factor using adjustment factors. Their findings indicate that, based on the Houston, Texas fixed factors, loss of productivity due to this factor can range from 5% to 25% when the design is incomplete at the construction start-time or normal lead times for items being processed. Borcherding et al. (1980) and Borcherding and Garber (1981) have also measured lost time due to this factor and presented subsequent effects on labor productivity.

The considerable influence of this factor on productivity has also been quantified in this research study. Table 5.34 presents the description of standard field conditions for logistics. Tables 5.35 and 5.36, and Figure 5.12 summarize results from this research study and compare them with other significant studies. Minor conditions involving one re-handling lifting or four-days-per-week materials availability yield an average productivity loss of seven percent. Moderate conditions requiring two to three re-handling lifting or two-to-three-days-per-week material availability bear an average productivity loss of 15%. Severe conditions involving more than three re-handling lifting or limited access time to materials bear an average productivity loss of 26%. These numbers are relatively low compared to those of MCA (1976), but somewhat similar to those of Neil and Knack (1984).

Table 5.34 Description of Standard Field Conditions for Logistics

Minor	**Moderate**	**Severe**
1 re-handling lifting, 4 days/week material availability	2 re-handling lifting, 2-3 days/week material availability	> 3 re-handling lifting, limited time

Table 5.35 Percentage of Productivity Loss for Logistics

Logistics	**Field Conditions**		
	Minor	**Moderate**	**Severe**
Mean	7	15	26
Median	6	15	25
Mode	10	10	20
Low	0	0	0
High	15	33	73
Range	15	33	73
Standard Deviation	3.6	7.1	14.0

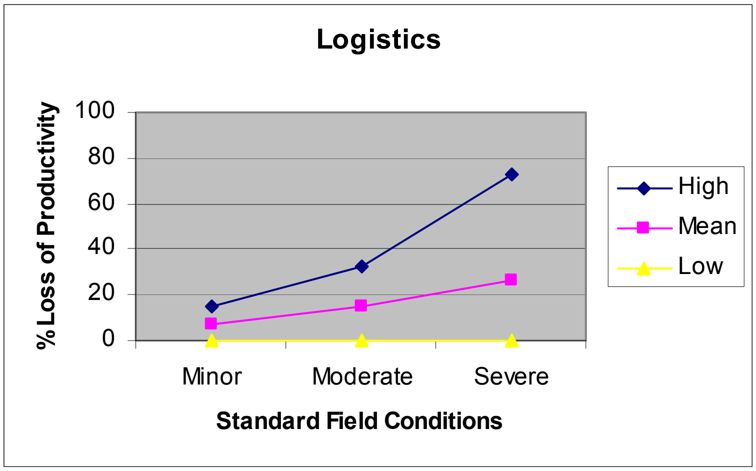


Figure 5.12 Loss of Productivity Due to Logistics

Table 5.36 Comparison Table of Loss of Productivity Due to Logistics

Logistics	Field Conditions		
	Minor	Moderate	Severe
Research Results	7%	15%	26%
MCA[1] (1976)	10%	25%	50%
Neil and Knack (1984)	5%	N/A	25%

[1] MCA – Mechanical Contractors Association of America

5.13 Fatigue

Fatigue of crew members is recognized as one of the major productivity factors and is interrelated with labor and morale. Fatigue is a physical or mental condition involving physical or mental stress, unusual physical exertion or long periods of overtime. This factor usually denotes changed conditions that entail physical exertion or other fatiguing activities causing lost time when an original plan resumes. A remote project can also result in fatigue because crews need to travel long distances to work (Bocherding and Alarcon, 1991). Furthermore, heavy materials and rework due to changes or engineering errors can cause physical fatigue. Although using large and heavy masonry units can increase productivity, it may result in a decrease in productivity if a long period of overtime exists. Findings from MCA(1976) have supported the notion that fatigue can contribute to significant loss of productivity. MCA (1976) estimates that, for minor, average, and severe conditions, losses of productivity are 8%, 10%, and 12%, respectively.

This research study revealed percentages significantly different from those of MCA (1976), as shown in Tables 5.38 and 5.39, and Figure 5.13. Table 5.37 presents the description of standard field conditions for fatigue. For minor conditions, when fatigue of crew members develops once a week, an average productivity loss of five percent exists, relatively small compared to one of MCA (1976). When disruptions proceed causing fatigue of crew members two or three times a week, the loss significantly increases to 11% on average. The rise increases to an average productivity loss of 20%, when the disruptions persist more than three times a week. It is recognized that productivity loss due to effects of fatigue significantly increases when disruptions are present more than once a week, and proceeds with a high rate of productivity loss if the disruptions continue.

Table 5.37 Description of Standard Field Conditions for Fatigue

Minor	**Moderate**	**Severe**
Once/week	2-3 times/week	Every day for more than 1 week

Table 5.38 Percentage of Productivity Loss for Fatigue

Fatigue	Field Conditions		
	Minor	Moderate	Severe
Mean	5	11	20
Median	5	10	20
Mode	5	10	20
Low	0	1	4
High	15	25	50
Range	15	24	46
Standard Deviation	3.7	6.2	10.6

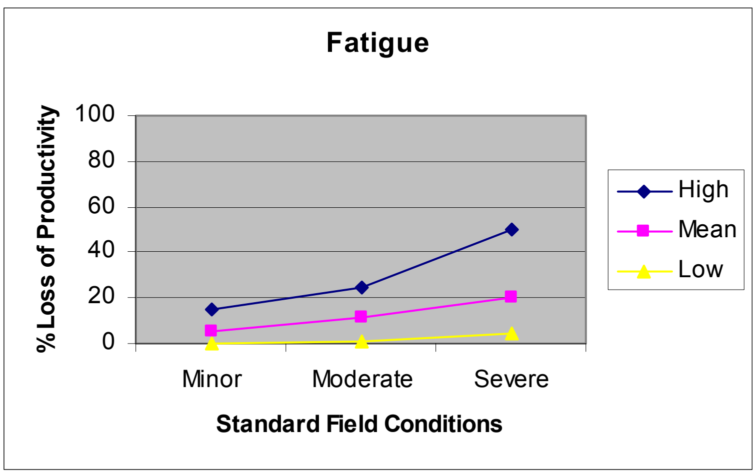


Figure 5.13 Loss of Productivity Due to Fatigue

Table 5.39 Comparison Table of Loss of Productivity Due to Fatigue

Fatigue	Field Conditions		
	Minor	Moderate	Severe
Research Results	5%	11%	20%
MCA[1] (1976)	8%	10%	12%

[1] MCA – Mechanical Contractors Association of America

5.14 Work Sequence

Disrupted work sequence or ripple effect is one of the most significant problems caused by changes. This factor highlights changes in other trades that consequentially affect the masonry contractor's own work, including rescheduling or changes in work sequence. Also, a disruption exists when there is significant lack of resources, when the work is performed in a congested area, or when out-of-sequence work is required (Thomas and Oloufa, 1995). MCA (1976) has presented percentages of productivity loss due to this ripple effect. It shows that productivity losses of 10%, 15%, and 20% are present for minor, average, and severe conditions. A recent research study performed by Thomas and Oloufa (1995) to determine the relationship between labor productivity and disruptions also accounted for ripple effect. Findings from this study indicate that one disruption per week results in a nine percent loss of performance for an average project. When the ripple effect is present, the required work-hours increase by an average order of magnitude of almost three, and as much as five for disrupted projects.

In this research study, particular efforts were called for in determining the estimates due to the effects of the disruption. Table 5.40 presents the description of standard field conditions for work sequence. Findings obtained from research investigations are presented in Figure 5.14, and Tables 5.41 and 5.42. The results show that minor conditions involving disruptions due to another trade or one change per week cause an average productivity loss of six percent. When two to three trades or changes per week disrupt masonry work, an average percent loss of productivity is approximately 14% similar to one of MCA (1976). However, the average loss increases significantly to approximately 23% when more than three trades or changes per week are present. This result is supported by the earlier findings of Thomas and Oloufa (1995).

Table 5.40 Description of Standard Field Conditions for Work Sequence

Minor	Moderate	Severe
One trade, one change/week	2 trades, 2-3 changes/week	Multiple trades, many changes

Table 5.41 Percentage of Productivity Loss for Work Sequence

Work Sequence	Field Conditions		
	Minor	Moderate	Severe
Mean	6	14	23
Median	5	10	20
Mode	5	10	20
Low	0	0	5
High	15	35	50
Range	15	35	45
Standard Deviation	3.8	7.5	11.7

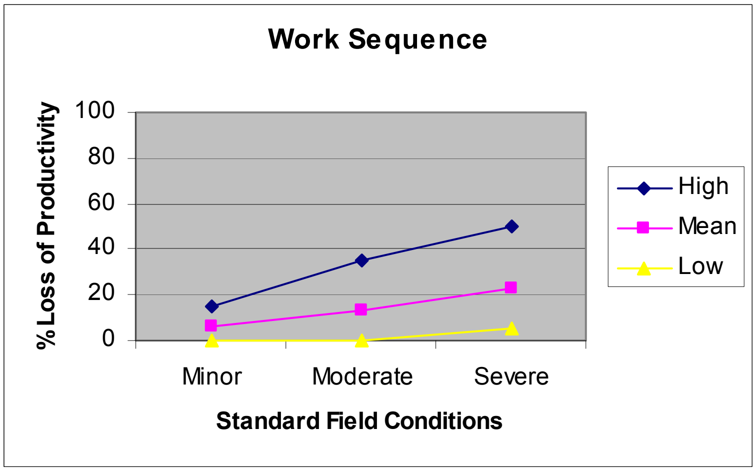


Figure 5.14 Loss of Productivity Due to Work Sequence

Table 5.42 Comparison Table of Loss of Productivity Due to Work Sequence

Work Sequence	Field Conditions		
	Minor	Moderate	Severe
Research Results	6%	14%	23%
MCA[1] (1976)	10%	15%	20%
Thomas and Oloufa (1995)	9%	N/A	23%

[1] MCA – Mechanical Contractors Association of America

5.15 Overtime

An extensive literature review shows that scheduled overtime can result in significant productivity loss in construction. This factor addresses any changed conditions that require overtime causing masonry workers to perform less efficiently than expected under the normal schedule, a schedule of eight-hours-per-day, five-days-per-week. The productivity loss normally results from physical fatigue, poor mental attitude and management inefficiency (Borcheding and Alarcon, 1991).

Overtime may also results in poor workmanship, while increasing accidents and absenteeism.

In recent years, there have been numerous investigations involved with overtime. Estimates presented by MCA (1976) show that losses of productivity due to this factor are 10%, 15%, and 20% for minor, average, and severe conditions, respectively. Business Roundtable (1980) states that overtime losses are not automatic but can range from none to approximately 25% for crews where there are no other factors involved (Thomas and Raynar 1994). In an effort to quantify productivity loss, Neil and Knack (1984) have shown that, based on the Houston, Texas fixed factors, there is a loss of productivity of about 10% for the following schedules: seven days of eight hours, six days of nine hours, and five days of 10 hours. Furthermore, a loss of productivity of 20% occurs for the following work schedules: seven days of 10 hours, six days of 11 hours, and five days of 12 hours.

Another significant study conducted by NECA (1989) indicates only small productivity losses when working isolated amounts of overtime. This study provides productivity data as a function of work days per week and work hours per day. It also introduces several tables showing a wide range of productivity loss data based on various numbers of work days per week and hours per work days.

Several extensive studies of the effects of scheduled overtime were sponsored by CII (CII, 1988; Thomas, 1990; Thomas and Raynar 1994). The findings of CII (1988) indicate that productivity loss from working overtime is not automatic and it is possible to work 60-hour weeks without serious productivity losses for several week periods of spot overtime (Schwartzkopf, 1995). This shows that productivity loss from short periods of overtime can be controlled by implementing effective management and support. Furthermore, Thomas and Raynar (1994) recently found that on average there is about a 15% loss of efficiency for weeks consisting of 50 and 60 hours.

Although these studies have varying results, the range of time is used for comparison purposes, and the results are shown in Table 5.45. Findings from several studies, including this one, are fairly consistent considering that each study considers a different combination of projects, trades, localities, and time. Table 5.44 and Figure 5.15 show a summary of this research study based on three different field conditions. Table 5.43 presents the description of standard field conditions for overtime. Minor conditions, referring to overtime of less than five hours per week for two consecutive weeks or less, result in an average productivity loss of seven percent. Moderate conditions, involving overtime of five to ten hours per week for three to five consecutive weeks, can generate an average productivity loss of 15%. More importantly, severe conditions involving overtime 11 hours or more per week for more than five consecutive weeks produce an average productivity loss of 24%. If there is a conflict condition, the higher number of hours or weeks may be applied. For instance, if there are 11-hours-per-week overtime for two consecutive weeks, this would be considered as a severe condition.

Table 5.43 Description of Standard Field Conditions for Overtime

Minor	Moderate	Severe
< 5 hours/week, 1-2 consecutive weeks	5-10 hours/week, 3-5 consecutive weeks	> 10 hours/week, > 5 consecutive weeks

Table 5.44 Percentage of Productivity Loss for Overtime

Overtime	Field Conditions		
	Minor	Moderate	Severe
Mean	7	15	24
Median	5	15	22
Mode	5	10	20
Low	0	0	3
High	15	35	50
Range	15	35	47
Standard Deviation	4.2	7.4	11.3

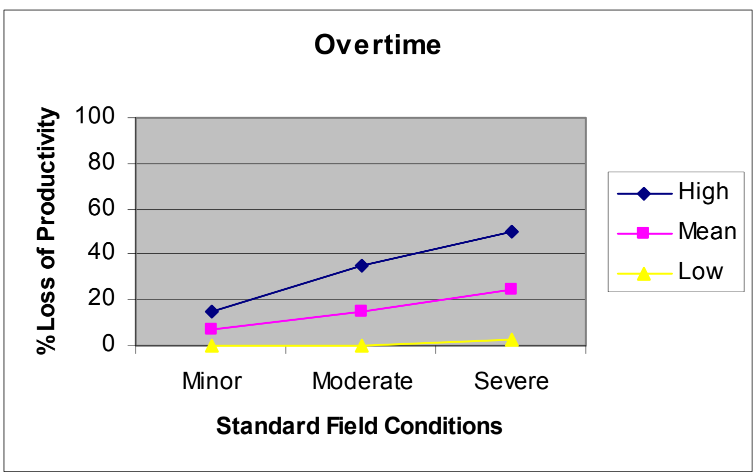


Figure 5.15 Loss of Productivity Due to Overtime

Table 5.45 Comparison Table of Loss of Productivity Due to Overtime

Overtime	Field Conditions		
	Minor	Moderate	Severe
Research Results	7%	15%	24%
BRT[I] (1980)	0%	N/A	25%
MCA[II] (1976)	10%	15%	20%
Neil and Knack (1984)	N/A	10%	20%
Thomas and Raynar (1994)	N/A	15%	N/A

[I] BRT – Business Roundtable
[II] MCA – Mechanical Contractors Association of America

5.16 Weather or Environment

An extensive review of the relevant studies has shown that external conditions in construction have significantly contributed to loss of productivity. Recently, numerous research studies have focused on adverse weather and environment, one of the most critical productivity factors in construction. This factor refers to differing site conditions from the estimating base due to natural forces such as severe weather, high humidity, high wind velocity, precipitation or snow, dusty or noisy conditions, or a combination of those. It is conceivable that adverse weather greatly affects construction operations and workers both physically and physiologically, thus slowing down the work. The impacts of adverse weather vary dramatically, but the greatest impacts are upon outside operations, particularly those involving earthmoving and temperature-and-weather-sensitive material such as concrete and mortar. In masonry construction, productivity is significantly influenced by low temperatures.

A significant number of research studies have focused on this factor. Several studies show that there is almost no effect on productivity until the temperature drops below 40ºF (Grimm and Wagner, 1974; Heather and Summers, 1996; NECA, 1974). In the year 1974, Grimm and Wagner established relationships between masonry productivity and temperature and humidity. Research results showed that masonry "productivity was found to decline as the temperature or humidity deviated from 75°F and 60%" (Grimm and Wagner, 1974). Based on the temperature of 75ºF and the humidity of 60%, they estimated a productivity loss of 10% and 22% when the temperature increased or decreased 5ºF and 10ºF, respectively. Moreover, when the temperature increased or decreased 15ºF, a productivity loss of about 30% was estimated. Another significant study published by MCA (1976) provides estimates of the effects of weather change. If the conditions are minor, average, and severe, the loss of productivity is 10%, 20%, and 30%, respectively.

In 1984, Neil and Knack presented adjustment factors for severe weather. Their findings show that productivity loss ranges from 5% to 25% when heavy protective clothing is required, heat and humidity are at discomfort levels, and/or wind and precipitation slow down workers activities, based on the Edmonson fixed factors for Houston, Texas. Furthermore, Koehn and Brown (1985) have determined two nonlinear equations showing relationships of productivity and temperature an humidity based on productivity data from other sources, such as NECA (1974) and Grimm and Wagner (1974) studies. A more recent research study conducted by

Thomas and Yiakoumis (1987) presents the factor model of construction productivity and investigates the effects of adverse weather on productivity based on three construction activities: masonry construction, structural steel erection, and framework erection.

Results from other research studies, including those of this research study, are presented in a comparison matrix as shown in Table 5.48. Although the sources are not directly related, a range of factors can be considered for comparison. These studies present results derived from both cold and hot weather. In this research study, field conditions were classified by the difference between the expected temperature and the actual temperature. Table 5.46 presents the description of standard field conditions for weather and environment. Minor, moderate and severe conditions indicate a temperature difference of 5ºF, 10ºF and 15ºF, respectively. Based on research results presented in Table 5.47 and Figure 5.16, the analysis shows an average productivity loss of 6%, 12% and 22% in minor, moderate and severe conditions, respectively.

Table 5.46 Description of Standard Field Conditions for Weather or Environment

Minor	**Moderate**	**Severe**
Expected temp. +5F in summer or -5F in winter	Expected temp. +10F in summer or -10F in winter	Expected temp. +15F in summer or -15F in winter

Table 5.47 Percentage of Productivity Loss for Weather or Environment

Weather or Environment	Field Conditions		
	Minor	Moderate	Severe
Mean	6	12	22
Median	5	10	20
Mode	5	10	20
Low	0	0	2
High	20	25	50
Range	20	25	48
Standard Deviation	4.6	6.2	10.9

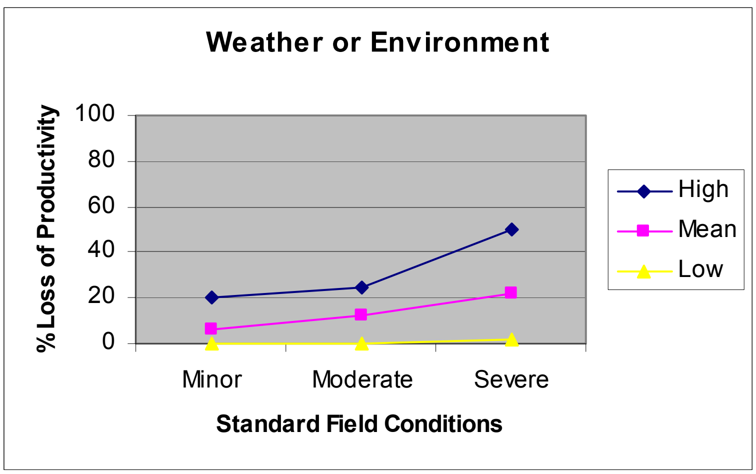


Figure 5.16 Loss of Productivity Due to Weather or Environment

Table 5.48 Comparison Table of Loss of Productivity Due to Weather or Environment

Weather or Environment	Field Conditions		
	Minor	Moderate	Severe
Research Results	6%	12%	22%
Grimm (1974)	10%	22%	30%
MCA[1] (1976)	10%	20%	30%

[1] MCA – Mechanical Contractors Association of America

5.17 Summary

This chapter outlined research findings and presented discussions of 16 field disruptions that commonly occur in masonry construction based on a national survey conducted throughout the U.S. For each factor, the research findings presented low, mean, and high percentages of productivity loss due to disruptions with minor, moderate, and severe conditions. Table 5.49 presents a summary of the findings in descending order sorted by the means of minor, moderate, and severe conditions, respectively. This table shows that logistics, overtime, and site access are the most influencing disruptions in masonry building construction. In addition, beneficial and joint occupancy are also significant disruptions for masonry contractors. In this chapter, findings from a number of studies were also discussed in comparison with the analysis results. The next chapter will test the research findings from this chapter through the development and validation of a model to determine loss of productivity.

Table 5.49 Summary of Percentages of Productivity Loss Due to Field Disruptions

No.	Field Disruptions	Estimated percentage of productivity loss (%), if the disruption is …								
		Minor			Moderate			Severe		
		Low	Mean	High	Low	Mean	High	Low	Mean	High
1	Logistics	0	**7**	15	0	**15**	33	0	**26**	73
2	Overtime	0	**7**	15	0	**15**	35	3	**24**	50
3	Site Access	0	**7**	15	0	**14**	30	0	**27**	60
4	Beneficial Occupancy	0	**7**	20	0	**14**	40	1	**25**	63
5	Joint Occupancy	0	**7**	20	0	**14**	35	4	**25**	50
6	Work Sequence	0	**6**	15	0	**14**	35	5	**23**	50
7	Diverted Supervision	0	**6**	15	2	**13**	30	5	**22**	55
8	Weather or Environment	0	**6**	20	0	**12**	25	2	**22**	50
9	Congestion	0	**5**	10	2	**12**	25	5	**24**	50
10	Labor Reassignment	0	**5**	15	2	**12**	30	2	**21**	50
11	Crew Size Change	0	**5**	15	3	**11**	25	5	**20**	50
12	Fatigue	0	**5**	15	1	**11**	25	4	**20**	50
13	Morale and Attitude	0	**4**	9	0	**12**	30	0	**21**	55
14	Errors and Omissions	0	**4**	8	2	**11**	25	4	**19**	45
15	Added Operations	0	**4**	10	2	**11**	25	4	**18**	40
16	Learning Curve	0	**4**	9	2	**11**	25	4	**18**	50

CHAPTER VI

VALIDATION OF THE HYPOTHESIS AND MODEL DEVELOPMENT AND VALIDATION

Significant findings presented in the previous chapter were utilized in the model development. This chapter presents the development and validation of the research model, created to estimate loss of productivity due to an impact of various field disruptions. Additionally, this chapter addresses practical steps for calculating loss of productivity based on the model obtained. Questionnaire issues, data collection, and data analysis for the model validation are also discussed. This chapter begins by detailing a validation of the research hypothesis and the development and implementation of the model, followed by model validation processes.

6.1 Validation of the Research Hypothesis

The hypothesis indicates that there are statistically significant differences among productivity loss of different severity levels of field conditions in a masonry building construction project, and considerable attention has been directed toward a validation of this hypothesis. In this study, the different severity levels of field conditions refer to three standard field conditions, minor, moderate, and severe. The mean differences of percentages of productivity loss (%PL) of these three standard conditions were tested through the use of the one-way ANOVA option in the SPSS®

9.05 for Windows[TM]. Sixteen ANOVA tables presenting the *F-statistic* and significance of three standard conditions for the 16 field disruptions were generated, and major findings from the tables are summarized in Table 6.1.

This table shows that the *F-statistics* are higher than 1.0 and the significances are less than 0.05 for all field disruptions. In other words, the *F-statistics* are extremely high and the significances are extremely low. That is, the research hypothesis is not rejected or there are statistically significant differences among means of productivity loss for the three different standard conditions for all disruptions. This table also presents means of %PL for the three standard conditions of all disruptions. The findings show that %PL increases as the level of severity in the construction field increases.

Table 6.1 Summary of Findings from ANOVA

No.	Field Disruptions	Field Conditions	Mean of %PL	Standard Deviation	Sample Size	*F-Statistic*	Significance
1	Congestion	Minor	5	2.91	112	174.71	0.000
		Moderate	12	5.79	110		
		Severe	24	11.92	114		
2	Morale and Attitude	Minor	4	2.03	94	105.28	0.000
		Moderate	12	7.40	113		
		Severe	21	11.93	112		
3	Labor Reassignment	Minor	5	3.14	112	133.01	0.000
		Moderate	12	6.35	113		
		Severe	21	11.41	113		
4	Crew Size Change	Minor	5	3.61	115	124.61	0.000
		Moderate	11	5.26	110		
		Severe	20	10.66	113		
5	Added Operations	Minor	4	1.89	95	150.33	0.000
		Moderate	11	5.35	112		
		Severe	18	8.29	108		
6	Diverted Supervision	Minor	6	3.40	115	107.83	0.000
		Moderate	13	7.07	114		
		Severe	22	12.88	112		
7	Learning Curve	Minor	4	2.04	98	104.03	0.000
		Moderate	11	6.13	114		
		Severe	18	10.10	110		
8	Errors and Omissions	Minor	4	1.88	97	129.61	0.000
		Moderate	11	5.84	114		
		Severe	19	9.57	110		
9	Beneficial Occupancy	Minor	7	5.50	116	93.25	0.000
		Moderate	14	8.93	115		
		Severe	25	14.14	114		
10	Joint Occupancy	Minor	7	4.43	116	150.98	0.000
		Moderate	14	7.09	116		
		Severe	25	11.27	114		
11	Site Access	Minor	7	4.28	111	141.35	0.000
		Moderate	14	7.24	112		
		Severe	27	12.96	116		
12	Logistics	Minor	7	3.62	108	121.57	0.000
		Moderate	15	7.10	111		
		Severe	26	14.02	116		
13	Fatigue	Minor	5	3.70	112	110.68	0.000
		Moderate	11	6.25	111		
		Severe	20	10.63	114		
14	Work Sequence	Minor	6	3.84	116	120.83	0.000
		Moderate	14	7.51	116		
		Severe	23	11.74	113		
15	Overtime	Minor	7	4.16	115	137.72	0.000
		Moderate	15	7.36	115		
		Severe	24	11.31	114		
16	Weather or Environment	Minor	6	4.65	116	126.48	0.000
		Moderate	12	6.25	111		
		Severe	22	10.88	113		

These findings were determined based on violations of two out of three basic assumptions for the one-way ANOVA. The first assumption was that the population distributions on the response variable were normal for all population groups. However, in this study, the distributions of means of productivity loss for standard conditions of the disruptions were not normal and had skewness ranging from -0.48 to 1.01 as shown in the summary of data analyses results shown in Appendix F. The second assumption stated that the standard deviations of the population distributions were equal for all population groups. However, the standard deviations of means of productivity loss range from 1.88 to 14.14, as shown in Table 6.1. The last assumption was that independent samples were collected from populations of all groups. The samples in this study were randomly gathered, and thereby meeting this assumption.

6.2 Model Development

One of the significant objectives of this research study is to develop a practical and effective model representing estimates of the negative effects of field disruptions on productivity. In this research study, particular attention was given to develop a model by considering its accuracy, completeness, and ease of implementation. The model includes mean, median, low, and high values of possible losses of productivity determined from the analyses. The numerical means and medians presented herein are used as estimates of productivity loss due to field disruptions because they are the most accurate point estimates of the sample population in this study. The low and high values are the minimum and maximum values, respectively, after several outliers and extremes were discarded from the database. The model representing mean, median, low, and high values of percentages of productivity loss due to the effects of field disruptions was constructed as shown in Table 6.2.

For practical use of the model, a copy of the standard conditions and definitions of field disruptions should be attached. These documents will assist in understanding the concept and terminologies of the model, as well as interpreting this model to a specific construction jobsite. Additionally, computational examples showing a process of implementing the model for estimating loss of productivity can be attached as well for reference. Along with these documents, the model is anticipated to be very useful for masonry practitioners in quantifying loss of productivity due to the effects of field disruptions.

Table 6.2 Model Presenting Low, Median, Mean, and High Values of Percentages of Productivity Loss

No.	**Field Disruptions**	**Estimated percentage of productivity loss (%), if the disruption is …**											
		Minor				**Moderate**				**Severe**			
		Low	**Median**	**Mean**	**High**	**Low**	**Median**	**Mean**	**High**	**Low**	**Median**	**Mean**	**High**
1	Congestion	0	5	**5**	10	2	10	**12**	25	5	20	**24**	50
2	Morale and Attitude	0	5	**4**	9	0	10	**12**	30	0	20	**21**	55
3	Labor Reassignment	0	5	**5**	15	2	10	**12**	30	2	20	**21**	50
4	Crew Size Change	0	5	**5**	15	3	10	**11**	25	5	20	**20**	50
5	Added Operations	0	5	**4**	10	2	10	**11**	25	4	16	**18**	40
6	Diverted Supervision	0	5	**6**	15	2	10	**13**	30	5	20	**22**	55
7	Learning Curve	0	5	**4**	9	2	10	**11**	25	4	15	**18**	50
8	Errors and Omissions	0	5	**4**	8	2	10	**11**	25	4	15	**19**	45
9	Beneficial Occupancy	0	5	**7**	20	0	10	**14**	40	1	20	**25**	63
10	Joint Occupancy	0	5	**7**	20	0	15	**14**	35	4	25	**25**	50
11	Site Access	0	5	**7**	15	0	15	**14**	30	0	25	**27**	60
12	Logistics	0	6	**7**	15	0	15	**15**	33	0	25	**26**	73
13	Fatigue	0	5	**5**	15	1	10	**11**	25	4	20	**20**	50
14	Work Sequence	0	5	**6**	15	0	10	**14**	35	5	20	**23**	50
15	Overtime	0	5	**7**	15	0	15	**15**	35	3	22	**24**	50
16	Weather or Environment	0	5	**6**	20	0	10	**12**	25	2	20	**22**	50

6.3 Implementation of the Model

The quantitative information provided in the model shows analysis results that can be utilized and modified to better estimate the required work-hours needed to perform certain work in field conditions that differ from original expectations. The estimators can also determine the increase in the required masonry work-hours, if project changes occur or field disruptions that are beyond the control of the masonry contractor are present. The following information is presented to propose a better understanding of how to apply the results. In this study, since the means given for any field disruptions are derived from the effects of that specific disruption with no effects of other disruptions involved, an additive approach is adopted to determine the effects of multiple field disruptions. The additive approach was used in this study because it was recommended and implemented by Neil and Knack (1984) to predict labor productivity. It was also commonly used to quantify the total productivity loss due to mechanical disruptive factors presented by MCA (1976).

To estimate the impact of field disruptions in this study, there are two classification methods based on whether the factors are applied prospectively or retrospectively (Dieterle and DeStephanis, 1992). If one would like to prospectively estimate the lost work-hours (LWH) for anticipated differences after a contract award, the estimated %PL of expected factors should be added and multiplied by the estimated work-hours (EWH), as shown in Equation 6.1.

On the other hand, if one would like to retrospectively quantify the lost work-hours for construction claims, the estimated %PL of actual factors should be added and then applied in Equation 6.2. One can also employ Equations 6.3 to 6.5 to retrospectively quantify total lost work-hours (TLH), actual work-hours (AWH), and unexplained hours (UPH), respectively.

Prospectively

$$LWH = EWH \times (\%PL) \qquad \text{(Equation 6.1)}$$

Retrospectively

$$LWH = TWH - [TWH / (1 + \%PL)] \qquad \text{(Equation 6.2)}$$

$$TLH = TWH - EWH \qquad \text{(Equation 6.3)}$$

$$AWH = TWH - LWH \qquad \text{(Equation 6.4)}$$

$$UPH = TLH - LWH \qquad \text{(Equation 6.5)}$$

Where: LWH = Lost Work-hours | EWH = Estimated Work-hours

%PL = Percentage of Productivity Loss | TWH = Total Work-hours

TLH = Total Lost Hours | AWH = Actual Work-hours

UPH = Unexplained Hours

The following examples are presented to promote a better understanding of how to use the model and the formulas, and an additive approach is adopted to determine additional work-hours due to several field disruptions. Example 1 shows that if the expected number of work-hours lost due to moderate congestion and moderate diverted supervision is 250 hours for a 1,000-hour job, then the total estimated work-hours required to perform the masonry work is 1,250 hours. With the same disruptions, but retrospectively, example 2 shows that if the actual work-hours equals 1,500 hours and the original work-hours was 1,000 hours, then the total lost work-hours is 500 hours. The total lost work-hours include two components: 300 lost work-hours due to differing field conditions that were beyond the control of the masonry contractor, and 200 unexplained work-hours probably to be absorbed by the masonry contractor. As a result, the actual work-hours required for the masonry work was only 1,200 hours.

Example 1: To prospectively estimate the lost work-hours due to field disruptions.

Before or during the masonry construction, the estimator figures the total estimated work-hours at 1,000 hours, and moderate congestion and moderate diverted supervision are expected. The expected work-hours lost and total predicted work-hours required for the work can be determined as follows.

A. Total estimated masonry work-hours (EWH) = 1,000 hours

B. Field factors (means from the model)

No. 1 Congestion (Moderate) shows an average productivity loss of 12%

No. 6 Diverted Supervision (Moderate) shows an average productivity loss of 13%

Total percentage of productivity loss (%PL) = 12% + 13% = 25% (or 0.25)

C. Expected work-hours lost due to the anticipated field factors

(LWH) = 1,000 x 0.25 = 250 hours

D. Total predicted work-hours required to perform the work

(A + C) = 1,000 + 250 = 1,250 hours

Example 2: To retrospectively estimate the lost work-hours due to field disruptions.

After completion of the masonry work, the estimator determines that the actual work-hours equals 1,500 hours, whereas the original estimated work-hours was 1,000 hours. During the masonry construction, moderate congestion and moderate diverted supervision were present. The lost work-hours can be determined as follow.

A. Total estimated masonry work-hours (EWH) = 1,000 hours

B. Total actual masonry work-hours (TWH) = 1,500 hours

C. Total lost work-hours (TLH) = 1,500 – 1,000 = 500 hours

D. Field factors (means from the model)

No. 1 Congestion (Moderate) shows an average productivity loss of 12%

No. 6 Diverted Supervision (Moderate) shows an average productivity loss of 13%

Total percentage of productivity loss (%PL) = 12% + 13% = 25% (or 0.25)

E. Work-hours lost due to the field factors (LWH) = 1,500 – [1,500/(1+0.25)]

= 300 hours

F. Work-hours lost due to unexplained conditions (UPH) = 500 – 300

= 200 hours

G. Actual work-hours required without disruptions (AWH) = 1,500 – 300

= 1,200 hours

6.4 Model Validation Questionnaire

The primary goal of the model validation process is to determine the accuracy of the model based on actual masonry construction projects. Particular efforts were made in the development of the validation questionnaire and data collection. Based on the criteria discussed in Section 3.7.2, the researcher paid close attention to several aspects of the validation questionnaire including its accuracy, completeness, and understanding, while maintaining an appropriate time frame for each interview session. The researcher felt that an interview of less than one hour was the proper time frame to allow the researcher to describe all necessary information to the participant and to gather all necessary data needed for the validation analysis. The essential information shared with the participant during the interview involved research objectives, benefits of this research study, questionnaire objectives, and characteristics of the questionnaire.

To facilitate the interview, the validation questionnaire was developed. The questionnaire involved both open-ended and closed-ended questions as well as the list of the 16 field disruptions and the standard conditions. The primary objective of the survey was to collect essential data needed for further analyses, so the questionnaire was classified into two parts. The first part of the questionnaire involved respondent and project profiles; it was partly adopted from the questionnaire conducted for the national survey study. Questions associated with the respondent profile basically included the respondent's position, contact information, and number of years of experience in masonry construction. Questions associated with the project profile primarily involved a project location, type of the project, project cost, and status of the project. The status of the project referred to "ongoing" or "completed." To better understand the nature of project characteristics for future analyses and recommendations, this part of the questionnaire included other questions related to project characteristics such as original and actual project durations, an incidence of project change orders, and a status of a project budget being “within” or “over” budget.

The second part of the questionnaire primarily involved two major components: masonry field disruptions and work-hours of the masonry crew during a certain period of time frame. Part of the questionnaire is shown in Figure 6.1. Based on the field disruptions and standard conditions, the researcher basically asked the participant whether any disruptions existed during the masonry work execution (Question B10). If so, the participant was expected to provide a list of the field disruptions associated with field conditions and a frequency of the incidence. Although it is generally necessary to provide a proof of the field conditions in a disputed case in litigation, providing such proof is out of the scope of this research study. The information in this study was therefore based on a database of the participant, oral evidence, or experience of the participant.

In accordance with the information given by the participant, the researcher determined whether the disruptions had occurred “very often” or “sometimes.” If the incidence was “very often,” the factor would be included in the analysis; otherwise, the researcher would postulate that the particular factor was a normal field condition, generally found and accepted in masonry construction. Thus, that particular factor would not be included in the analysis.

B.6 What was the original estimated work-hours for the masonry work? ________ hours

B.7 What was the actual work-hours for the masonry work? ________ hours

B.8 How do you rate the incidence of change orders on this masonry work?

☐ Above average ☐ Average ☐ Below average

B.9 How do you rate the amount of rework on this masonry work?

☐ Above average ☐ Average ☐ Below average

B.10 What were major field factors affecting masonry productivity on this project? What was their condition level? *(See the attachment for factor numbers and condition levels.)* How often were the disruptions present?

Factor No.	Field Condition	Frequency of the Incidence	Time Frame of the Incidence
	☐ Minor ☐ Moderate ☐ Severe	☐ Very often ☐ Sometimes	
	☐ Minor ☐ Moderate ☐ Severe	☐ Very often ☐ Sometimes	
	☐ Minor ☐ Moderate ☐ Severe	☐ Very often ☐ Sometimes	

Figure 6.1 Part of the Validation Questionnaire Involving Field Disruptions and Work-hours of Masonry Crew

The participant was also required to provide a time frame of the incidence based on his or her database or direct experience with the project. If the masonry work experienced a field disruption during most of the work period, the factor would be included in the analysis. If the masonry work encountered a field disruption that was not for the whole period of the work, a proportional approach would be implemented to determine work-hours used for calculating loss of work-hours. For instance, if expected work-hours of the masonry crew is 1,000 hours and it is assumed that during only 60% of the total work-hours congestion was experienced, only 600 hours of the estimated work-hours are appropriated as expected work-hours used for further calculation. In this research study, none of the participants provided physical evidence of the time frame of an incidence, so the data obtained were based on his or her direct experience and the researcher's judgment. The participant was also welcome to provide additional field disruptions that existed at the construction field, if not included in the given list of the 16 field disruptions. One participant suggested that an accident should have been included in the list. Even though a major accident results in a significant impact on productivity, the researcher felt that a major accident is not foreseeable, and an accident results in other disruptions, such as morale and attitude, already included in the list. As a result, an accident was not added to the list of the field disruptions.

In addition to the masonry field disruptions, work-hours of the masonry crew during a certain period of time was also an important topic and was addressed in the second part of the questionnaire (Questions B.6 and B.7). The originally estimated and actual work-hours were based on a database of each participant. For completed projects, the appropriate time frame used to determine the work-hours included the whole project execution period. For ongoing projects, however, the appropriate time frame began with the start of the masonry work continued to the time of the interview. Estimated work-hours and actual work-hours during that period were observed and used for a calculation of productivity loss in the analysis.

To better understanding the masonry work characteristics, the second part of the questionnaire also included other questions associated with original and updated schedules of the masonry work, any incidence of masonry change orders (Question B.8), any amount of rework (Question B.9), and the status of the masonry work budget (being "within" or "over" budget). These items were necessary to comprehensively explain the characteristics of masonry work of a project.

6.5 Data Collection for Model Validation

In this study, the researcher first approached two residential construction managers of the Office of Facilities Planning and Construction (OFPC) at the University of Texas at Austin (UT) to identify validation projects. After several interviews had been conducted, a total of ten qualified masonry projects managed by six masonry contractors were nominated by the two construction managers. Essential information in relation to the nominated projects and masonry contractors' representatives were identified. The obtained project information included a project type, a project location, project cost and schedule, project status, and change order of the project. The information regarding the masonry contractors' representatives included names of the companies, names of contact persons, phone numbers, and company addresses.

Initial contacts by phone calls to the six prospective masonry contractors' representatives in charge of the ten masonry projects were completed first. The participants were owners, chief estimators, or project engineers of the masonry contractors. During the first phone conversation, the researcher supplied useful information to the participants, including the objectives of the research study and validation survey, as well as benefits of the study to masonry contractors. Out of six prospective participants, three participants were interested in joining the research study, resulting in a total of five masonry projects. These participants were interviewed between February 15, 2001 to April 15, 2001. All interviews were conducted at the participant's office located in Texas. The interviews were conducted to collect data by questioning the participants face-to-face, and the participants were able to have a copy of the questionnaire. After the interviews, the data from the interview session were input into the Microsoft Excel® 2000 spreadsheets for future data analysis.

This research study proceeded with a descriptive analysis to reveal essential information of the validation projects, masonry projects, and participants. Characteristics of the validation projects and masonry work are summarized in Table 6.3. Based on the descriptive analysis conducted for the model development phase, the model was developed from projects with four major classifications including 1) industrial/commercial, 2) educational/governmental, 3) residential, and 4) restoration/renovation projects. The project samples were obtained from educational projects so they can be used for the model validation process. All five projects were located in Austin, Texas. The total project cost of these projects was over $120 million, while the total cost of subcontracted masonry work was over $7.6 million. Findings from the interviews revealed that all projects were completed or were likely to be completed within budget, but only one project was completed or was likely to be completed on-time. The masonry work on four projects was completed or was likely to be completed within budget. The masonry work on two projects was completed or was likely to be completed on-time. In addition, the descriptive analysis showed that three out of five masonry work projects were completed, whereas two masonry work projects were being constructed during the time of the interview.

Referring to characteristics of participants, as shown in Table 6.4, there were two owners and one chief estimator of masonry contractors participating in the model validation survey. The first masonry contractor's representative (MCR1) was in charge of projects one to three, whereas the second and third ones (MCR 2 and MCR 3) were in charge of projects four and five, respectively. All participants had more than 20 years of experience in masonry construction. Table 6.5 refers to qualifications of two OFPC representatives (OR1 and OR2). They were both residential construction managers with more than 20 years of experience in building construction related to masonry work.

Table 6.3 Characteristics of Validation Projects and Masonry Work

Project No.	Project Type	Location	Masonry Work Status
1	Parking Garage 1	Austin, Texas	complete
2	Office Building	Austin, Texas	ongoing
3	Parking Garage 2	Austin, Texas	complete
4	School Building	Austin, Texas	ongoing
5	Student Dormitory	Austin, Texas	complete

Table 6.4 Characteristics of Masonry Contractor's Representatives

Project No.	Masonry Contractor's Representative	Position	Experience
1	MCR 1	Owner	More than 20 years
2	MCR 1	Owner	More than 20 years
3	MCR 1	Owner	More than 20 years
4	MCR 2	Project	More than 20 years
5	MCR 3	Owner	More than 20 years

Table 6.5 Characteristics of Owner Company's Representatives

Project No.	OFPC Representative	Position	Experience
1	OR 1	Construction Manager	More than 20 years
2	OR 1	Construction Manager	More than 20 years
3	OR 1	Construction Manager	More than 20 years
4	OR 1	Construction Manager	More than 20 years
5	OR 2	Construction Manager	More than 20 years

6.6 Analysis for Model Validation

A significant research effort had been made to analyze the data obtained from five validation projects associated with three owners or chief estimators of masonry contractors. The primary purpose of the data analysis was to determine the accuracy of the developed model providing estimates of productivity loss due to the effects of various field disruptions. Moving toward this purpose, this research study conducted two analysis approaches.

The first approach was to identify differences in the estimated %PL computed from the model and the actual %PL computed from the data collected in the model validation process. After the descriptive analysis was conducted, the data stored in the Microsoft Excel® 2000 spreadsheets were used for calculation to determine the estimated and actual %PL. An additive approach was used to compute total estimated means of %PL due to multiple disruptions. The steps taken to accurately determine the required values by the first approach are listed as shown below.

1. Study essential information of the validation projects.

2. List actual field disruptions along with a condition.

3. Compute an estimated %PL by using factor means from the model.

4. Compute an actual %PL by using the estimated and actual work-hours.

5. Compare the total %PL calculated from the 3rd step and the actual %PL calculated from the 4th step.

In an effort to validate the model, the researcher first studied the necessary information of all validation projects. This information was gathered based on the discussions with the masonry contractors' representatives. Five validation projects faced various disruptions during the project execution. To enhance an understanding of each project, a summary of significant facts of the projects, such as disruptive factors and masonry crew composition, are presented in Appendix D. This substantial information led to the discussion of a number of field disruptions the masonry crew faced. Particular attention was paid to the interpretation of the information, to generate a list of field disruptions. Based on the standard conditions, a list of field disruptions along with their conditions is given in Table 6.6. The researcher then examined factors, in accordance with each disruption and its condition, from the model. With respect to an additive approach, a summation of a total %PL was estimated, as shown in Table 6.6.

The next step was to calculate an actual %PL for each factor by using the estimated and actual work-hours collected from the validation projects. The estimated work-hours were originally calculated without any disruptions taken into account, and the estimated and actual work-hours were assumed to be accurate data. The results of the calculation are summarized in Table 6.7. The actual %PL was then compared with the estimated %PL computed by using the model, and a comparison table was compiled as shown in Table 6.8. This table revealed that a certain difference in these two values existed. The calculations show that four out of five estimated losses were higher than the actual ones, and differences between estimated and actual productivity losses ranges from -2 to 19%.

Table 6.6 Steps 2 and 3 of the First Validation Approach - Computation of Estimated Percentages of Productivity Loss

Project No.	Disruption	Condition	Estimated % PL by Model
			Mean (%)
1	1. Congestion	Minor	5
	11. Site Access	Minor	7
	Total for Project 1		12
2	10. Joint Occupancy	Moderate	14
	14. Work Sequence	Moderate	14
	Total for Project 2		28
3	1. Congestion	Moderate	12
	Total for Project 3		12
4	2. Morale and Attitude	Severe	21
	6. Diverted Supervision	Minor	6
	8. Errors and Omissions	Moderate	11
	Total for Project 4		38
5	1. Congestion	Minor	5
	Total for Project 5		5

Table 6.7 Step 4 of the First Validation Approach - Computation of Actual Percentages of Productivity Loss

Project No.	Estimated Work-Hours (EWH)	Total Work-Hours (TWH)	Total Loss of Work-Hours (TLH)	Actual %PL by Projects
	Work-Hours	Work-Hours	Work-Hours	%
	(a)	(b)	(c) = (b)-(a)	(c)/(a) x 100
1	21,000	22,000	1,000	5
2	11,000	12,000	1,000	9
3	26,000	28,000	2,000	8
4	43,025	56,000	12,975	30
5	55,000	59,000	4,000	7

Table 6.8 Step 5 of the First Validation Approach -
Comparison Between Estimated and Actual Percentage of Productivity Loss

Project No.	**Estimated % PL by Model from Table 6.6**	**Actual %PL by Projects from Table 7.7**	**Difference in Estimated and Actual %PL**
	%	%	%
	(d)	(e)	(d)-(e)
1	12	5	7
2	28	9	19
3	12	8	4
4	38	30	8
5	5	7	-2

The second approach for examining the accuracy of the model was to determine whether the actual %PL of the validation projects fell within the inter-quartile range (*IQR*) of the data distribution, containing approximately 50% of the data. The range was constructed based on the raw data collected in the model validation process. The *IQR* for each validation project was conducted through the use of the 126 data sets previously used to develop the model prior to eliminating outliers and extremes in the data screening process. An additive approach was used to determine a total estimated %PL if the validation project experienced several disruptions. As a result, a new set of data containing the 129 total estimated %PL due to several disruptions was determined. Through the use of the boxplot option from SPSS® 9.05 for Windows™, the new data set's outliers and extremes were identified and discarded prior to constructing the *IQR* for each project using SPSS® 9.05 for

Windows™. A summary of the descriptive analysis for the new data set is presented in Appendix F. The *IQR*s for data of all validation projects were examined, and graphically presented in Figure 6.2. The *IQR* is presented as the box representing the difference between the 25th and 75th percentiles (approximately 50% of the data). A bold asterisk mark shown in this figure represents the actual %PL computed based on the validation projects, whereas the ends of lines that extend from the box are the lowest and highest values of the data. This figure shows that the actual %PL of projects 3 and 4 fall within their *IQR*.

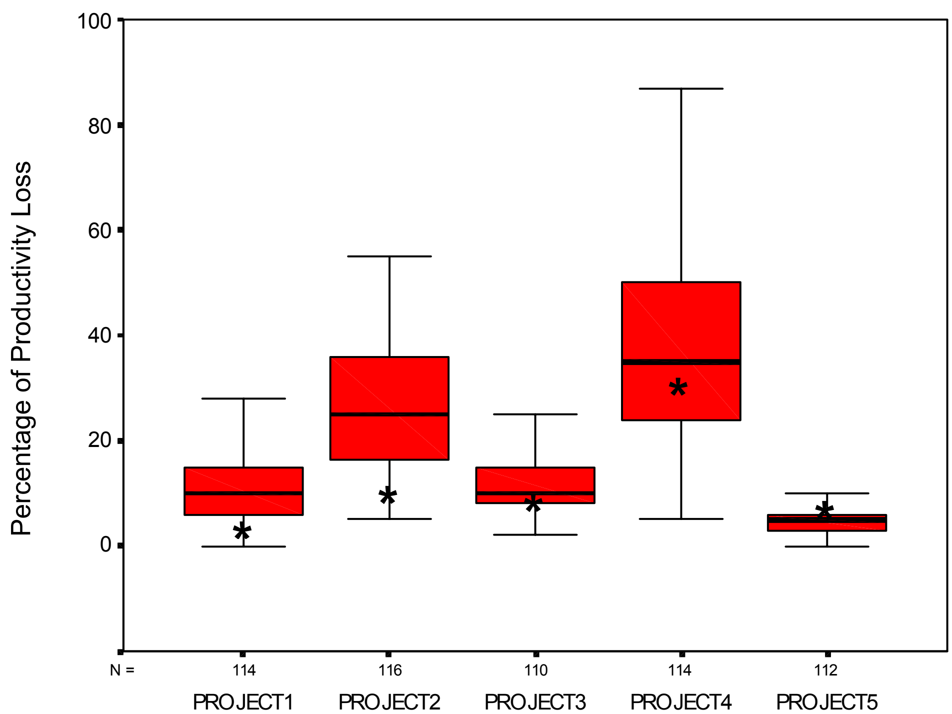


Figure 6.2 Actual Percentages of Productivity Loss and Inter-Quartile Ranges

The *IQR*s and the actual %PL computed using the validation projects data are also summarized in Table 6.9. In addition, this table presents the minimum and maximum values of the predicted data. Table 6.9 also shows that the actual %PL for projects 3 and 4 fall within their *IQR*. The other three projects fall within the 1^{st} and 4^{th} quartiles of predicted percentages of productivity loss.

Table 6.9 Analysis Results of the Second Validation Approach

Project No.	**Low**	**25th Percentile**	**75th Percentile**	**High**	**Actual %PL by Projects from Table 6.7**
1	0	6	15	28	5
2	5	16	36	55	9
3	2	8	15	25	8
4	5	24	50	90	30
5	0	3	6	10	7

6.7 Summary

The validation process for the research hypothesis was discussed first in this chapter, and according to the analysis it was not rejected. In other words, there were statistically significant differences among %PL of the standard field conditions of the 16 disruptions. The analysis also showed that %PL of all disruptions increased as the level of severity increased. Moreover, this chapter proposed a research model for estimating the impact of field disruptions in masonry construction based on the given standard conditions. The value of a model arises from its effective implementation and the understanding of its uses. Therefore, this chapter presented mathematical formulas and samples for determining the loss of work-hours due to field disruptions. After the model and formulas were presented, a model validation was conducted to determine the accuracy of the model. The analyses showed that there was a range from -2 to 19% difference in the estimated and actual %PL, based on the five validation projects. Furthermore, the analyses showed that two out of the five projects had actual %PL fall within their *IQR*, and the other three projects fall within the 1st and 4th quartiles of predicted percentages of productivity loss.

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

This chapter presents conclusions from the research investigations and offers recommendations for future research. The research objectives are first reviewed and specific conclusions relating to these objectives are discussed. Several key conclusions of the research findings and the research hypothesis are presented. Finally, research contributions of this study are addressed.

7.1 Review of Research Objectives

The five objectives established in Chapter One are summarized below:

1. *To identify productivity loss factors in the construction industry*: An extensive literature review revealed that there are numerous productivity factors in construction. These factors were classified into seven categories as shown in Section 2.3. Due to the great number of productivity factors, this research study had focused on 16 common field disruptions as shown in Table 4.1.

2. *To develop standard conditions of common field disruptions for masonry*: As presented in Table 4.3, the standard conditions were established and used as a basis for quantifying the effects of field disruptions.

3. *To present quantitative values of productivity loss based on statistical analysis, and compare the results with other studies*: The means of productivity loss

were presented and compared with results from other studies as shown in Chapter Five. The research findings were based on the national survey responses of 152 masonry contractors.

4. *To develop a model providing estimates of productivity loss due to the effects of field disruptions in masonry construction*: The model used to estimate productivity loss due to field disruptions was presented in Table 6.2. This model presents a summary of average percentages of productivity loss due to the 16 field disruptions, based on the standard conditions. This model also presents medians and ranges of percentages of productivity loss.

5. *To validate the model with actual project data*: The developed model was tested for its accuracy in estimate of productivity loss due to field disruptions, using five masonry construction projects of masonry contractors in Texas.

7.2 Findings

The following key findings from the research effort are listed below.

- An extensive literature review presented numerous productivity factors and their common causes and effects regarding loss of productivity. This study identified common field disruptions affecting labor productivity in masonry building construction. A list of the 16 field disruptions with their description that was earlier presented in Table 4.1 is shown in Table 7.1.

- The hypothesis that there are statistically significant differences among average productivity loss of different severity levels of field conditions in a masonry building construction project was validated. The results also showed that the percentages of productivity loss tended to increase as the severity levels of field conditions increased.
- This study developed a model and definition of standard field conditions for minor, moderate, and severe impacts for the 16 factors. The results can be used to estimate productivity loss in terms of lost work-hours due to field conditions that differ from original expectations. The standard conditions and model that were earlier presented in Tables 4.3 and 6.2 are shown in Tables 7.2 and 7.3, respectively. Based on the standard field conditions, the model presents a summary of low, median, mean, and high percentages of productivity loss due to the 16 field disruptions.

Table 7.1 Major Field Disruptions in Masonry Construction

No.	Field Factors	Description
1	Congestion	Change prohibits use of optimum crew size including physically limited working space and material storage.
2	Morale and Attitude	Change involves excessive inspection, multiple change orders and rework, schedule disruption, or poor site conditions.
3	Labor Reassignment	Change demands rescheduling or expediting, and results in lost time to move out/in.
4	Crew Size Change	Change increases or decreases in optimum crew size resulting in inefficiency or workflow disruption.
5	Added Operations	Change disrupts ongoing work due to concurrent operations.
6	Diverted Supervision	Change causes distraction of supervision to analyze and plan changed work, stop and re-plan ongoing work, or reschedule work.
7	Learning Curve	Change causes workers to lost time while becoming familiar with and adjusting to new work or a new environment.
8	Errors and Omissions	Change causes time lost due to mistakes engendered by changed circumstances.
9	Beneficial Occupancy	Change requires the use of premises by owner prior to work completion, restricted work access, or working in close proximity to owner's personnel or equipment.
10	Joint Occupancy	Change requires work to be done while other trades not anticipated in the bid occupy the same area.
11	Site Access	Change requires inconvenient access to work area, inadequate workspace, remote materials storage, or congested worksite.
12	Logistics	Change involves unsatisfactory supply of materials by owner or general contractor, causing inability to control material procurement, and delivery and re-handling of substituted materials.
13	Fatigue	Change involves unusual physical exertion causing lost time when original plan resumes.
14	Work Sequence	Change causes lost time due to changes in other contractors' work.
15	Overtime	Change requires overtime causing physical fatigue and poor mental attitude.
16	Weather or Environment	Change involved work in very cold or hot weather, during high humidity or in dusty or noisy environment.

Table 7.2 Standard Conditions of Field Disruptions

No.	Field Factors	Standard Field Conditions		
		Minor	**Moderate**	**Severe**
1	Congestion	An additional crew/contractor working in the same area 1 day/week	Additional crews/contractors working in the same area 2-3 days/week	Additional crews/contractors working in the same area everyday
2	Morale and Attitude	Less than 3 inspections/week, average 1 hour each	Daily inspection, 1-2 hours each	Full time inspection
3	Labor Reassignment	Crews move once a week between job areas	Crews move 2-3 times/week between job areas	Crews move almost daily between jobs
4	Crew Size Change	Crew size changes once/week	Crew size changes 2-3 times/week	Crew size changes almost daily
5	Added Operations	Work disrupted once/week	Work disrupted 2-3 times/week	Work disrupted almost daily
6	Diverted Supervision	2 times/week, 1-2 hours	Daily, 1-2 hours	Daily, 4 hours or more
7	Learning Curve	Once a week	2-3 times/week	Daily
8	Errors and Omissions	Every 2 weeks or more	Every week	Every 1 or 2 day(s)
9	Beneficial Occupancy	Punch list work	Punch list and new work one week prior to the original completion date	Many crews and overtime a few days prior to the original completion date
10	Joint Occupancy	Facility partly occupied, one trade working	Facility partly occupied, 2-3 trades working in the same area	Facility in operation, work on limited shifts
11	Site Access	4 days/week, < 25 yards to materials storage	2-3 days/week, 25-50 yards to materials storage	Once/week, > 50 yards to materials storage
12	Logistics	1 re-handling lifting, 4 days/week material availability	2 re-handling lifting, 2-3 days/week material availability	> 3 re-handling lifting, limited time
13	Fatigue	Once/week	2-3 times/week	Every day for more than 1 week
14	Work Sequence	One trade, one change/week	2 trades, 2-3 changes/week	Multiple trades, many changes
15	Overtime	< 5 hours/week, 1-2 consecutive weeks	5-10 hours/week, 3-5 consecutive weeks	> 10 hours/week, > 5 consecutive weeks
16	Weather or Environment	Expected temp. +5F in summer or -5F in winter	Expected temp. +10F in summer or -10F in winter	Expected temp. +15F in summer or -15F in winter

Table 7.3 Model Presenting Low, Median, Mean, and High Values of Percentages of Productivity Loss

No.	Field Disruptions	Estimated percentage of productivity loss (%), if the disruption is …											
		Minor				Moderate				Severe			
		Low	Median	Mean	High	Low	Median	Mean	High	Low	Median	Mean	High
1	Congestion	0	5	**5**	10	2	10	**12**	25	5	20	**24**	50
2	Morale and Attitude	0	5	**4**	9	0	10	**12**	30	0	20	**21**	55
3	Labor Reassignment	0	5	**5**	15	2	10	**12**	30	2	20	**21**	50
4	Crew Size Change	0	5	**5**	15	3	10	**11**	25	5	20	**20**	50
5	Added Operations	0	5	**4**	10	2	10	**11**	25	4	16	**18**	40
6	Diverted Supervision	0	5	**6**	15	2	10	**13**	30	5	20	**22**	55
7	Learning Curve	0	5	**4**	9	2	10	**11**	25	4	15	**18**	50
8	Errors and Omissions	0	5	**4**	8	2	10	**11**	25	4	15	**19**	45
9	Beneficial Occupancy	0	5	**7**	20	0	10	**14**	40	1	20	**25**	63
10	Joint Occupancy	0	5	**7**	20	0	15	**14**	35	4	25	**25**	50
11	Site Access	0	5	**7**	15	0	15	**14**	30	0	25	**27**	60
12	Logistics	0	6	**7**	15	0	15	**15**	33	0	25	**26**	73
13	Fatigue	0	5	**5**	15	1	10	**11**	25	4	20	**20**	50
14	Work Sequence	0	5	**6**	15	0	10	**14**	35	5	20	**23**	50
15	Overtime	0	5	**7**	15	0	15	**15**	35	3	22	**24**	50
16	Weather or Environment	0	5	**6**	20	0	10	**12**	25	2	20	**22**	50

- Even though the model was developed based on the national survey, there are some limitations to the model. This model focused on 16 disruptive factors affecting masonry labor productivity that are beyond the direct control of a masonry contractor, and result in productivity loss. Using the model may generate a difference between the estimated and actual estimates of productivity loss, if other productivity factors not listed in the model are present on a construction project. Also, using the model for other construction trades or misinterpreting the standard conditions may result in an inaccurate prediction of productivity loss.
- Among the 16 field disruptions presented, logistics, overtime, and site access are the most influencing disruptions in masonry building construction. As shown in Table 5.49, these disruptions present the highest means of percentages of productivity loss.
- Using the five validation projects, it was found that the differences in the estimated and actual percentages of productivity loss ranged from -2 to 19%. Furthermore, two out of five validation projects had actual percentages of productivity loss fall within the inter-quartile ranges of predicted values using the model data. The other three projects fall within the 1st and 4th quartiles of predicted percentages of productivity loss as calculated from the predicted data. This finding could be the result of several factors which occurred during the research investigations. In this study, the model was developed with

significant variances in the data. This could be the result of data collected from experience and databases of project participants, rather than actual field observations of empirical data on construction projects. Furthermore, in the validation process, actual percentages of productivity loss were computed based on estimated and actual work-hours of the masonry crew. These two numbers might be imprecise due to various issues such as the inaccuracy in estimates and the existence of other factors affecting productivity.

- Based on the model validation process, it is possible that productivity loss due to the impact of disruptions varied based on several aspects including the individual contractor, the crew and the job. For example, each contractor had a different crew size with various equipment and materials. In addition, crew members from different projects may have had different levels of experience. Also, each job had different levels of difficulty in the work. These issues may have a significant impact on the productivity loss data collected through the validation process. Based in the lack of statistical validation, this model should be used as reference, and may require modifications based on other sources including historical databases, other research studies, industry-wide studies or experts. In addition, an expert in construction may be required to identify the existing disruptions in complex field conditions.

7.3 Recommendations for Future Research

Through the process of this research study, three major areas have been acknowledged as potential areas for future research. The first area involves the development of the model. An improved survey package can improve the accuracy and reliability of the model. In the survey sample, even though the sample productivity loss data provided were randomly selected and identical for all field disruptions, this consistency might have been an unintentional guide for survey responses on the questionnaire. Only part of the sample with concealed names of field disruptions should be presented in the survey package. Moreover, even though the standard conditions were proposed by the researcher and reviewed by several masonry practitioners, the study did not include experts in the construction field to validate the standard conditions. The expert and practitioner Delphi method is therefore recommended for future research. In this study, the analysis showed that there were high standard deviations for many field disruptions, especially with severe conditions, which indicated that a larger number of survey responses might be required to obtain more accurate percentages. In addition, the study focused only on 16 field disruptions for masonry building construction. A greater number of field disruptions for several construction trades should be compiled and studied for future research. Furthermore, the model was developed based on experience and databases of project participants, which might result in some bias. Field observations of actual empirical data on a large number of construction projects are recommended to increase the accuracy of the presented model.

The second potential area for future research is in the model validation used to determine the accuracy of the model. Using more cases with a variety of field disruptions should increase the accuracy of any conclusions that can be drawn from the analysis. In addition, the research findings were based on information orally provided by representatives of masonry contractors; no proof of information was shown. The proof of information can be verified by acquiring physical evidence from the representatives of masonry contractors, obtaining an agreement from the representative of the owner organization, and physically collecting data from the project. As previously stated, the research findings were also based on estimated and actual work-hours provided by the participants. These data may introduce inaccuracies due to various factors such as inaccurate estimates and the existence of other productivity factors in the field. Field observations of actual empirical data on a number of construction projects may improve precision of the computed values.

The last potential area for improvement in future research involves the use of the model. In this research study, the additive approach was employed to determine productivity loss due to the impact of multiple field disruptions. Alternative approaches, such as using a weighted factor, can be implemented and tested to improve accuracy and reliability of the model if several field disruptions are present. Lastly, this research study demonstrated the feasibility of developing an estimating model for masonry building construction. As such, a similar model for other construction areas, mechanical, electrical, etc. can be achieved to better estimate the impact of field disruptions.

7.4 Research Contributions

This research investigation contributes to the management body of knowledge by presenting a detailed list of 16 field disruptions and standard conditions for masonry building construction. This investigation also identified the relative impact of each disruption. This study will better enable masonry contractors to assess the required work-hours needed to perform certain work in field conditions that differ from original expectations. Additionally, if project changes occur, the model provides an indication of an increase or decrease on the required masonry labor. This study can also enable general contractors, architects, and owners to focus on implementing techniques to improve site conditions or minimize field disruptions. Since masonry contractors usually cannot control the field conditions, general contractors, architects, and owners will hopefully be able to recognize and minimize the additional work-hours required due to an impact of field disruptions, and thereby improve productivity.

APPENDICES

Appendix A National Survey Documents

MCAA

Mason Contractors Association of America
Productivity Loss in Masonry Work Due to Changed Conditions

Questionnaire

Date: ______________________ Company name: ________________________________

Respondent's name: ______________________________ Title: ____________________

Address: ____

Tel: ____________________ Fax: ________________ E-mail: ______________________

No.	Changed Condition	Estimated Percentage of Productivity Loss (%), If the Change Is ... *(0% to 100% in each column)*		
		Minor	Moderate	Severe
1	**Congestion**: Change prohibits use of optimum crew size including physically limited working space and material storage.			
2	**Morale and Attitude**: Change involves excessive inspection, multiple change orders and rework, schedule disruption, or poor site conditions.			
3	**Labor Reassignment**: Change demands rescheduling or expediting, and results in lost time to move out/in.			
4	**Crew Size Change**: Change increases or decreases in optimum crew size resulting in inefficiency or workflow disruption.			
5	**Added Operations**: Change disrupts ongoing work due to concurrent operations.			
6	**Diverted Supervision**: Change causes distraction of supervision to analyze and plan changed work, stop and re-plan ongoing work, or reschedule work.			
7	**Learning Curve**: Change causes workers to lost time while becoming familiar with and adjusting to new work or a new environment.			
8	**Errors and Omissions**: Change causes time lost due to mistakes engendered by changed circumstances.			
9	**Beneficial Occupancy**: Change requires the use of premises by owner prior to work completion, restricted work access, or working in close proximity to owner's personnel or equipment.			
10	**Joint Occupancy**: Change requires work to be done while other trades not anticipated in the bid occupy the same area.			
11	**Site Access**: Change requires physically inconvenient access to work area, inadequate workspace, remote materials storage, or poor man-lift management.			
12	**Logistics**: Change involves unsatisfactory supply of materials by owner or general contractor, causing inability to control material procurement, and delivery and re-handling of substituted materials.			
13	**Fatigue**: Change involves unusual physical exertion causing lost time when original plan resumes.			
14	**Work Sequence**: Change causes lost time due to changes in other contractors' work.			
15	**Overtime**: Change requires overtime causing physical fatigue and poor mental attitude.			
16	**Weather or Environment**: Change involved work in very cold or hot weather, during high humidity or in dusty or noisy environment.			

Note: This table had been modified from Appendix B published in Management Methods Bulletin No.CO1, File Change Orders, Mechanical Contractors Association of America, Inc., Rockville, MD.

Please return this questionnaire by mail or fax to:
Jeff Buczkiewicz, Mason Contractors Association of America, 1910 S. Highland Ave., Suite 101, Lombard, IL 60148
Tel: 1-800-536-2225, Fax: 630-705-4209 By September 29, 2000

MCAA

Mason Contractors Association of America
Productivity Loss in Masonry Work Due to Changed Conditions

Examples of Minor/Moderate/Severe Conditions

No.	Changed Condition	Examples of Minor/Moderate/Severe Conditions		
		Minor	Moderate	Severe
1	**Congestion**: Change prohibits use of optimum crew size including physically limited working space and material storage.	An additional crew/contractor working in the same area 1 day/week	Additional crews/contractors working in the same area 2-3 days/week	Additional crews/contractors working in the same area everyday
2	**Morale and Attitude**: Change involves excessive inspection, multiple change orders and rework, schedule disruption, or poor site conditions.	Less than 3 inspections/week, average 1 hour each	Daily inspection, 1-2 hours each	Full time inspection
3	**Labor Reassignment**: Change demands rescheduling or expediting, and results in lost time to move out/in.	Crews move once a week between job areas	Crews move 2-3 times/week between job areas	Crews move almost daily between jobs
4	**Crew Size Change**: Change increases or decreases in optimum crew size resulting in inefficiency or workflow disruption.	Crew size changes once/week	Crew size changes 2-3 times/week	Crew size changes almost daily
5	**Added Operations**: Change disrupts ongoing work due to concurrent operations.	Work disrupted once/week	Work disrupted 2-3 times/week	Work disrupted almost daily
6	**Diverted Supervision**: Change causes distraction of supervision to analyze and plan changed work, stop and re-plan ongoing work, or reschedule work.	2 times/week, 1-2 hours	Daily, 1-2 hours	Daily, 4 hours or more
7	**Learning Curve**: Change causes workers to lost time while becoming familiar with and adjusting to new work or a new environment.	Once a week	2-3 times/week	Daily
8	**Errors and Omissions**: Change causes time lost due to mistakes engendered by changed circumstances.	Every 2 weeks or more	Every week	Every 1 or 2 day(s)
9	**Beneficial Occupancy**: Change requires the use of premises by owner prior to work completion, restricted work access, or working in close proximity to owner's personnel or equipment.	Punch list work	Punch list and new work one week prior to the original completion date	Many crews & overtime a few days prior to the original completion date
10	**Joint Occupancy**: Change requires work to be done while other trades not anticipated in the bid occupy the same area.	Facility partly occupied, one trade working	Facility partly occupied, 2-3 crews working in the same area	Facility in operation, work on limited shifts
11	**Site Access**: Change requires inconvenient access to work area, inadequate workspace, remote materials storage, or congested worksite.	4 days/week, < 25 yards to materials storage	2-3 days/week, 25-50 yards to material storage	Once/week, > 50 yards to material storage
12	**Logistics**: Change involves unsatisfactory supply of materials by owner or general contractor, causing inability to control material procurement, and delivery and re-handling of substituted materials.	1 re-handling lifting, 4 days/week material availability	2 re-handling lifting, 2-3 days/week material availability	> 3 re-handling lifting, limited time
13	**Fatigue**: Change involves unusual physical exertion causing lost time when original plan resumes.	Once/week	2-3 times/week	Every day for more than 1 week
14	**Work Sequence**: Change causes lost time due to changes in other contractors' work.	One trade/ one change/week	2 trades/ 2-3 changes/week	Multiple trades, many changes
15	**Overtime**: Change requires overtime causing physical fatigue and poor mental attitude.	< 5 hours/week, 1-2 consecutive weeks	5-10 hours/week, 3-5 consecutive weeks	> 10 hours/week, > 5 consecutive weeks
16	**Weather or Environment**: Change involved work in very cold or hot weather, during high humidity or in dusty or noisy environment.	Expected Temp. +5F in summer or -5F in winter	Expected Temp. +10F in summer or -10F in winter	Expected Temp. +15F in summer or -15F in winter

Note: This table had been modified from Appendix B published in Management Methods Bulletin No.CO1, File Change Orders, Mechanical Contractors Association of America, Inc., Rockville, MD.

MCAA

Mason Contractors Association of America
Productivity Loss in Masonry Work Due to Changed Conditions

Questionnaire - Example -

Date: mm/dd/yy Company name: ABC Company

Respondent's name: First Name Last Name Title: Chief Estimator

Address: Street Address, City, State, Country, Zip Code

Tel: (Area Code) 123-4567 Fax: (Area Code) 012-3456 E-mail: EmailAddress@Server.com

No.	Changed Condition	Estimated Percentage of Productivity Loss (%), If the Change Is ... *(0% to 100% in each column)*		
		Minor	Moderate	Severe
1	**Congestion**: Change prohibits use of optimum crew size including physically limited working space and material storage.	4	9	[illegible]
2	**Morale and Attitude**: Change involves excessive inspection, multiple change orders and rework, schedule disruption, or poor site conditions.	4	[illegible]	15
3	**Labor Reassignment**: Change demands rescheduling [illegible] expediting, and results in lost time to move [illegible]	4	9	15
4	**Crew Size Change**: Change increases [illegible] optimum crew size resulting in inefficiency [illegible] disruption.	[illegible]	9	15
5	**Added Operations**: [illegible] ongoing work due to concurrent operations.	4	9	15
6	**Diverted Supervision**: Change causes [illegible] supervision to analyze and plan changed work, [illegible] ongoing work, or reschedule work.	4	9	15
7	**Learning Curve**: [illegible] causes workers to lost time while becoming familiar with and adjusting to new work or a new environment.	4	9	15
8	**Errors and Omissions**: Change causes time lost due to mistakes engendered by changed circumstances.	4	9	15
9	**Beneficial Occupancy**: Change requires the [illegible] by owner prior to work completion, restri[illegible] access, or working in close proximity to owner's [illegible] equipment.	4	[illegible]	15
10	**Joint Occupancy**: [illegible] work to be done while other trades not anticip[illegible] occupy the same area	[illegible]	9	15
11	**Site Access**: Change requires inconvenient [illegible] inadequate workspace, remote materials sto[illegible] congested worksite.	4	9	15
12	**Logistics**: Change involves [illegible] supply of materials by owner or g[illegible] causing inability to control material procurement [illegible] and re-handling of substituted materials.	4	9	15
13	**Fatigue**: Change involves unusual physical exertion causing lost time when original plan resumes.	4	9	15
14	**Work Sequence**: Change causes lost time due to changes in other contractors' work.	4	9	15
15	**Overtime**: Change requires overtime causing physical fatigue and poor mental attitude.	4	9	15
16	**Weather or Environment**: Change involved work in very cold or hot weather, during high humidity or in dusty or noisy environment.	4	9	15

Fill All Boxes with the Percentage of Productivity Loss

Example Only (Not a Guideline)

Note: This table had been modified from Appendix B published in Management Methods Bulletin No.CO1, File Change Orders, Mechanical Contractors Association of America, Inc., Rockville, MD.

Please return this questionnaire by mail or fax to:
Jeff Buczkiewicz, Mason Contractors Association of America, 1910 S. Highland Ave., Suite 101, Lombard, IL 60148
Tel: 1-800-536-2225, Fax: 630-705-4209 By September 29, 2000

MCAA

Mason Contractors Association of America
Productivity Loss in Masonry Work Due to Changed Conditions

An Example of Masonry-Hours Loss Computation

A. Estimated masonry hours	1,000
B. Actual masonry hours (payroll)	1,200
Therefore, total man-hours lost (B-A)	200

C. A site factor causing masonry-hours lost, if your project has the following condition (selected by a masonry contractor)

From sample survey data

No. 11 Site Access,	Moderate Change	9%

D. Computation

Man-hours lost due to the changed condition	= 1,000 x (0.09)
	= 90 hours
Total man-hours lost (from B)	= 200 hours
Lost due to unexpected conditions or subcontractor	= 200 – 90
	= 110 hours

Appendix B Validation Survey Documents

FIELD FACTORS SURVEY

Field Factors Affecting Masonry Labor Productivity

Please take a few minutes to complete this questionnaire. **All individual responses will be kept confidential.**

Date: ______________________

Respondent's Name (optional) ____

Respondent Title (optional) ____

Company's Name (optional) ____

PART A: RESPONDENT & PROJECT PROFILES

A.1 Are you a representative of the owner, general contractor or masonry contractor on this project?

☐ Owner ☐ General Contractor ☐ Masonry Contractor

A.2 How many years of experience do you have in masonry building construction?

☐ 0-5 years ☐ 6-10 years ☐ 11-20 years ☐ More than 20 years

A.3 What is the project name? ____

A.4 Where is this project located? *(city, state, country)* ____

A.5 What type of facility was constructed?

☐ Industrial/commercial ☐ Educational/governmental ☐ Residential

☐ Restoration/renovation ☐ Other (please specify ________________________)

A.6 What is the total estimated cost of this project? $______________

A.7 Was the overall project completed within budget?

☐ Yes ☐ No

A.8 What was the original schedule duration for this project? ________ months

A.9 What was the actual duration for this project? ________ months

A.10 How do you rate the incidence of change orders on this project?

☐ Above average ☐ Average ☐ Below average

A.11 How do you rate the amount of rework on this project?

☐ Above Average ☐ Average ☐ Below average

PART B: MASONRY WORK

B.1 What was the total estimated cost of the masonry work for this project? $________________

B.2 Was the masonry work completed within budget?

☐ Yes ☐ No

B.3 What was the original schedule duration for the masonry work? ________ months

B.4 What was the actual duration for the masonry work? ________ months

B.5 What was the typical masonry crew composition for this masonry work? *(Please indicate the number of workers)*

_______ Bricklayers _______ Other (please specify ____________________)

_______ Bricklayer helpers _______ Other (please specify ____________________)

B.6 What was the original estimated man-hours for the masonry work? ________ hours

B.7 What was the actual man-hours for the masonry work? ________ hours

B.8 How do you rate the incidence of change orders on this masonry work?

☐ Above average ☐ Average ☐ Below average

B.9 How do you rate the amount of rework on this masonry work?

☐ Above average ☐ Average ☐ Below average

B.10 What were major field factors affecting masonry productivity on this project? What was their condition level? *(See the attachment for factor numbers and condition levels.)* How often were the disruptions present?

Factor No.	Field Condition	Frequency of the Incidence	Time Frame of the Incidence
	☐ Minor ☐ Moderate ☐ Severe	☐ Very often ☐ Sometimes	
	☐ Minor ☐ Moderate ☐ Severe	☐ Very often ☐ Sometimes	
	☐ Minor ☐ Moderate ☐ Severe	☐ Very often ☐ Sometimes	
	☐ Minor ☐ Moderate ☐ Severe	☐ Very often ☐ Sometimes	
	☐ Minor ☐ Moderate ☐ Severe	☐ Very often ☐ Sometimes	
	☐ Minor ☐ Moderate ☐ Severe	☐ Very often ☐ Sometimes	
	☐ Minor ☐ Moderate ☐ Severe	☐ Very often ☐ Sometimes	
	☐ Minor ☐ Moderate ☐ Severe	☐ Very often ☐ Sometimes	

B.11 What were other field factors not listed in the attachment? What was their condition level? How often were they present?

Factor No.	Field Condition	Description of the Condition	Frequency of the Incidence	Time Frame of the Incidence
	☐ Minor ☐ Moderate ☐ Severe		☐ Very often ☐ Sometimes	
	☐ Minor ☐ Moderate ☐ Severe		☐ Very often ☐ Sometimes	
	☐ Minor ☐ Moderate ☐ Severe		☐ Very often ☐ Sometimes	
	☐ Minor ☐ Moderate ☐ Severe		☐ Very often ☐ Sometimes	
	☐ Minor ☐ Moderate ☐ Severe		☐ Very often ☐ Sometimes	
	☐ Minor ☐ Moderate ☐ Severe		☐ Very often ☐ Sometimes	
	☐ Minor ☐ Moderate ☐ Severe		☐ Very often ☐ Sometimes	
	☐ Minor ☐ Moderate ☐ Severe		☐ Very often ☐ Sometimes	

THANK YOU FOR YOUR TIME AND COOPERATION

Would you like to receive the survey results? If "Yes", please provide your name and address or email address.

☐ Yes ☐ No

ATTACHMENT

Field Factors and Standard Conditions

No.	Field Factors	Standard Field Conditions		
		Minor	Moderate	Severe
1	**Congestion**: Change prohibits use of optimum crew size including physically limited working space and material storage.	An additional crew/contractor working in the same area 1 day/week	Additional crews/contractors working in the same area 2-3 days/week	Additional crews/contractors working in the same area everyday
2	**Morale and Attitude**: Change involves excessive inspection, multiple change orders and rework, schedule disruption, or poor site conditions.	Less than 3 inspections/week, average 1 hour each	Daily inspection, 1-2 hours each	Full time inspection
3	**Labor Reassignment**: Change demands rescheduling or expediting, and results in lost time to move out/in.	Crews move once a week between job areas	Crews move 2-3 times/week between job areas	Crews move almost daily between jobs
4	**Crew Size Change**: Change increases or decreases the optimum crew size resulting in inefficiency or workflow disruption.	Crew size changes once/week	Crew size changes 2-3 times/week	Crew size changes almost daily
5	**Added Operations**: Change disrupts ongoing work due to concurrent operations.	Work disrupted once/week	Work disrupted 2-3 times/week	Work disrupted almost daily
6	**Diverted Supervision**: Change causes distraction of supervision to analyze and plan changed work, stop and re-plan ongoing work, or reschedule work.	2 times/week, 1-2 hours	Daily, 1-2 hours	Daily, 4 hours or more
7	**Learning Curve**: Change causes workers to lost time while becoming familiar with and adjusting to new work or a new environment.	Once a week	2-3 times/week	Daily
8	**Errors and Omissions**: Change causes lost time due to mistakes engendered by changed circumstances.	Every 2 weeks or more	Every week	Every 1 or 2 day(s)
9	**Beneficial Occupancy**: Change requires the use of premises by owner prior to work completion, restricted work access, or working in close proximity to owner's personnel or equipment.	Punch list work	Punch list and new work one week prior to the original completion date	Many crews and overtime a few days prior to the original completion date
10	**Joint Occupancy**: Change requires work to be done while other trades not anticipated in the bid occupy the same area.	Facility partly occupied, one trade working	Facility partly occupied, 2-3 trades working in the same area	Facility in operation, work on limited shifts
11	**Site Access**: Change requires inconvenient access to work area, inadequate workspace, remote materials storage, or congested worksite.	4 days/week, < 25 yards to materials storage	2-3 days/week, 25-50 yards to materials storage	Once/week, > 50 yards to materials storage
12	**Logistics**: Change involves unsatisfactory supply of materials by owner or general contractor, causing inability to control material procurement, and delivery and re-handling of substituted materials.	1 re-handling lifting, 4 days/week material availability	2 re-handling lifting, 2-3 days/week material availability	> 3 re-handling lifting, limited time
13	**Fatigue**: Change involves unusual physical exertion causing lost time when original plan resumes.	Once/week	2-3 times/week	Every day for more than 1 week
14	**Work Sequence**: Change causes lost time due to changes in other contractors' work.	One trade, one change/week	2 trades, 2-3 changes/week	Multiple trades, many changes
15	**Overtime**: Change requires overtime causing physical fatigue and poor mental attitude.	< 5 hours/week, 1-2 consecutive weeks	5-10 hours/week, 3-5 consecutive weeks	> 10 hours/week, > 5 consecutive weeks
16	**Weather or Environment**: Change involves work in very cold or hot weather, during high humidity or in a dusty or noisy environment.	Expected Temp. +5F in summer or -5F in winter	Expected Temp. +10F in summer or -10F in winter	Expected Temp. +15F in summer or -15F in winter

Note: This table had been modified from Appendix B published in Management Methods Bulletin No.CO1, File Change Orders, Mechanical Contractors Association of America, Inc., Rockville, MD.

Appendix C Data Collected from the National Survey

No.	Respondent	Congestion			Morale & Attitude			Labor Reassignment			Crew Size Change		
		Mi	Mo	Se	Mi	Mo	Se	Mi	Mo	Se	Mi	Mo	Se
1	AL1	10	25	40	10	30	60	10	20	30	10	15	20
2	AZ1	3	21	33	7	25	30	4	11	21	5	9	30
3	AZ2	5	15	25	2	5	5	2	7	12	5	10	12
4	CA1	0	3	5	0	0	0	0	3	5	0	7	12
5	CA10	30	50	80	20	20	40	10	15	25	10	20	50
6	CA11	5	10	15	8	17	20	5	8	12	10	15	20
7	CA2	5	8	20	5	10	35	2	5	10	2	5	10
8	CA3	5	5	25	5	40	40	5	40	50	5	15	25
9	CA4	5	10	15	5	10	15	5	10	15	5	10	20
10	CA5	5	12	20	2	3	5	2	5	20	3	8	10
11	CA6	5	25	55	5	20	25	0	10	20	5	10	20
12	CA7	5	10	15	5	10	15	5	10	20	5	10	20
13	CA8	3	5	25	5	10	15	2	5	10	5	10	15
14	CA9	20	30	40	5	8	15	10	15	25	5	5	10
15	CO1	20	40	50	10	30	40	15	35	45	20	30	60
16	CO2	2	6	10	3	9	15	3	10	15	4	8	16
17	CO3	0	3	10	3	5	12	5	12	20	2	4	7
18	CO4	2	6	10	3	9	15	3	10	15	4	8	16
19	CT1	2	5	10	1	1	1	2	5	10	1	3	5
20	FL1	5	15	20	5	10	15	2	5	10	5	15	20
21	FL2	3	6	20	3	5	12	2	8	15	5	6	25
22	GA1	2	12	18	5	25	35	2	15	20	2	10	15
23	HI1	5	15	25	10	15	20	5	15	25	5	15	25
24	ID1	20	40	70	20	40	60	30	50	70	20	40	60
25	IL1	1	15	65	2	10	70	5	20	50	4	8	80
26	IL10	6	10	20	8	15	25	10	18	25	10	15	30
27	IL11	10	20	30	4	8	12	2	4	7	7	10	14
28	IL12	10	30	50	5	20	40	5	20	40	10	20	30
29	IL2	10	15	20	5	10	15	10	15	20	10	15	20
30	IL3	7	12	20	5	15	20	5	10	15	2	5	10
31	IL4	5	10	20	10	15	20	5	10	15	3	5	10
32	IL5	3	6	12	2	12	18	5	15	25	3	8	15
33	IL6	5	15	30	10	30	50	10	20	30	5	10	15
34	IL7	0	10	20	10	20	35	0	5	10	0	5	10
35	IL8	10	15	20	5	7	9	3	5	7	6	8	10
36	IL9	5	10	15	0	5	10	2	7	10	5	10	15
37	IN1	5	22	35	5	30	40	3	10	25	6	15	40
38	IN2	3	5	8	4	7	8	2	4	10	4	8	12
39	IN3	0.5	2	20	0.5	3	10	1	5	20	2	7	15
40	IN4	5	15	25	5	15	35	10	20	40	10	20	30
41	IN5	10	15	25	0	0	0	5	10	20	5	10	20
42	KY1	10	30	50	5	15	45	3	8	25	2	9	15
43	KY2	7	15	20	10	20	25	3	15	20	3	10	30

Note: Mi, Mo, and Se represent minor, moderate, and severe field conditions, respectively.

No.	Respondent	Congestion			Morale & Attitude			Labor Reassignment			Crew Size Change		
		Mi	Mo	Se	Mi	Mo	Se	Mi	Mo	Se	Mi	Mo	Se
44	MA1	3	8	17	3	6	10	3	8	17	0	10	20
45	MA2	5	10	20	5	10	20	5	10	20	5	10	20
46	MD1	10	15	25	5	10	20	5	8	15	5	10	25
47	MD2	10	20	30	5	8	12	5	10	25	10	15	25
48	MD3	5	8	12	7	10	17	3	6	9	3	6	9
49	MD4	4	11	23	4	10	16	6	19	32	4	9	18
50	MD5	10	20	30	5	8	12	5	10	25	10	15	25
51	ME1	10	25	45	5	15	25	5	15	25	5	15	25
52	MI1	5	15	30	4	10	20	10	15	40	3	10	15
53	MI2	3	10	20	5	20	20	0	15	50	2	10	30
54	MI3	2	5	20	2	15	33	0	5	15	0	5	20
55	MI4	5	8	15	5	10	10	2.5	7	12	0	5	8
56	MN1	2	10	50	0	5	25	2	10	20	10	25	50
57	MN2	5	15	20	2	3	5	0	6	12	0	3	7
58	MO1	10	20	35	15	20	30	10	20	35	5	8	10
59	MO2	5	10	25	10	25	30	5	10	20	3	10	25
60	MO3	10	20	40	10	35	35	15	30	30	10	40	40
61	MO4	3	10	25	5	10	15	10	20	30	10	15	20
62	MO5	3	6	15	2	5	10	4	10	18	1	3	5
63	MT1	5	10	15	4	8	10	15	25	40	10	15	20
64	NC1	25	35	50	5	15	20	5	10	15	5	7	10
65	NC2	5	15	20	15	30	70	5	5	30	3	8	12
66	ND1	2	4	10	0	7.5	15	0	5	5	0	5	7
67	NH1	5	10	20	3	5	10	10	15	20	0	5	10
68	NJ1	0	10	20	0	5	10	0	10	20	0	10	20
69	NV1	10	25	30	20	40	40	15	25	25	10	35	35
70	NY1	10	15	20	15	20	40	5	20	35	0	5	10
71	NY2	5	10	25	5	10	25	3	8	15	3	8	15
72	NY3	5	20	50	10	25	60	10	20	50	10	15	25
73	NY4	2	5	8	2	6	10	3	5	8	4	6	12
74	NY5	3	10	20	2	7	15	2	7	15	2	5	10
75	OH1	5	13	25	3	9	30	3	5	8	3	5	8
76	OH2	8	28	60	10	20	35	10	25	45	5	15	25
77	OH3	0	5	20	0	5	25	0	15	30	0	10	25
78	OH4	10	25	50	5	15	25	5	25	40	10	20	30
79	OH5	2	8	12	2	8	12	5	10	15	0	5	8
80	OH6	2	5	10	5	10	20	2	5	8	2	5	8
81	OH7	5	12	20	4	8	15	8	10	18	6	12	20
82	OH8	2	10	20	0	2	7	2	5	10	1	3	5
83	OH9	3	7	12	5	9	12	3	5	12	4	10	18
84	OR1	5	17	28	5	5	5	1	5	10	5	10	20
85	OR2	5	10	25	5	10	20	5	10	15	5	5	5
86	OR3	5	12	20	3	11	30	7	15	25	10	20	30

Note: Mi, Mo, and Se represent minor, moderate, and severe field conditions, respectively.

No.	Respondent	Congestion			Morale & Attitude			Labor Reassignment			Crew Size Change		
		Mi	Mo	Se	Mi	Mo	Se	Mi	Mo	Se	Mi	Mo	Se
87	PA1	2	10	25	0	5	8	7	20	30	0	8	15
88	PA2	5	10	20	5	10	20	5	10	25	10	20	30
89	PA3	15	60	75	15	50	75	5	50	75	25	65	75
90	PA4	10	20	50	5	15	40	10	20	50	10	15	20
91	PA5	5	10	20	5	10	20	5	15	30	0	10	15
92	SC1	20	30	35	15	20	30	30	40	75	50	70	90
93	SC2	10	20	35	5	10	15	10	20	30	10	20	30
94	SC3	6	20	50	2	10	25	8	25	60	5	15	30
95	TN1	5	10	20	5	10	20	5	10	20	5	10	20
96	TN2	5	17.5	50	9	22.5	57.5	7.5	25	65	5.5	20	40
97	TN3	4	12	22	6	18	35	6	15	27	6	15	22
98	TX1	7	14	30	15	25	35	6	15	25	10	20	35
99	TX10	8	24	40	4	12	20	8	24	40	5	15	25
100	TX11	5	15	20	15	20	25	10	20	30	15	25	35
101	TX12	5	10	20	5	10	20	10	20	33	15	30	50
102	TX2	10	15	30	10	20	30	5	18	30	10	20	30
103	TX3	10	21	30	28	35	42	10	35	40	10	25	35
104	TX4	8	16	30	10	15	20	8	12	20	8	12	20
105	TX5	20	25	45	5	15	20	10	25	50	10	30	60
106	TX6	10	20	30	15	30	50	10	20	35	15	30	50
107	TX7	3	10	20	1	5	10	1	5	20	2	10	20
108	TX8	20	40	80	4	35	70	2	28	60	5	35	70
109	TX9	3	10	35	10	25	55	15	40	60	25	50	75
110	UT1	5	15	30	5	10	15	5	12	25	5	10	20
111	VA1	10	30	50	5	15	25	5	10	15	10	30	50
112	VA2	5	10	15	10	20	30	5	10	15	5	10	15
113	VA3	4	8	10	4	9	15	3	8	10	5	8	10
114	VA4	10	30	50	5	10	20	15	20	40	2	10	30
115	VA5	15	25	35	10	20	30	10	20	30	10	20	30
116	VA6	5	10	20	10	30	40	5	5	10	10	15	20
117	VA7	5	15	20	10	20	30	5	10	15	2	10	15
118	VT1	3	7	15	2	10	20	3	7	20	3	10	15
119	WA1	5	10	15	5	10	10	2	5	8	5	5	10
120	WA2	5	10	20	2	5	10	2	5	10	10	20	50
121	WA3	2	5	10	1	2	5	2	8	15	2	5	10
122	WI1	3	6	12	3	6	12	4	8	16	3	6	12
123	WI2	5	15	30	5	15	30	2	5	10	5	15	30
124	WI3	2	4	5	1	2	3	1	2	2	3	4	6
125	WI4	10	25	50	10	30	50	15	25	30	15	30	50
126	WI5	15	50	85	8	8	60	12	22	50	25	25	50
127	WI6	5	10	15	5	10	20	5	10	20	5	10	15
128	WV1	2	6	12	0	5	10	5	8	12	5	10	20
129	WY1	5	10	20	5	10	15	5	10	20	5	10	20

Note: Mi, Mo, and Se represent minor, moderate, and severe field conditions, respectively.

No.	Respondent	Added Operations			Diverted Supervision			Leraning Curve			Errors & Omissions		
		Mi	Mo	Se	Mi	Mo	Se	Mi	Mo	Se	Mi	Mo	Se
1	AL1	20	30	40	10	20	30	10	20	30	20	30	40
2	AZ1	10	18	40	8	20	63	10	22	34	15	25	35
3	AZ2	3	7	11	7	18	25	2	4	6	2	6	10
4	CA1	0	3	10	15	40	50	5	10	15	2	5	10
5	CA10	25	50	75	10	15	20	5	10	15	15	25	40
6	CA11	5	5	8	10	12	15	5	5	5	3	5	8
7	CA2	2	4	8	0	3	10	2	4	10	4	8	20
8	CA3	5	5	25	5	40	50	1	5	10	5	10	50
9	CA4	10	15	25	5	10	20	5	10	20	5	10	15
10	CA5	3	10	20	2	6	12	2	5	12	3	5	10
11	CA6	0	5	15	5	10	25	0	10	25	0	5	15
12	CA7	5	10	20	5	10	15	5	10	15	5	10	15
13	CA8	5	10	25	2	5	10	2	4	6	2	5	10
14	CA9	10	15	15	30	30	30	8	15	21	6	10	15
15	CO1	10	20	30	10	20	30	30	50	80	15	20	35
16	CO2	2	6	10	2	25	75	2	6	10	1	2	6
17	CO3	5	15	30	2	5	12	3	7	15	1	3	7
18	CO4	2	6	10	2	25	75	2	6	10	1	2	6
19	CT1	1	3	5	1	3	5	1	3	5	1	3	5
20	FL1	2	6	10	4	10	20	5	10	20	4	8	15
21	FL2	5	10	15	4	9	30	4	10	15	3	5	10
22	GA1	8	24	30	10	25	32	4	12	18	1	5	10
23	HI1	5	15	25	10	20	30	4	10	15	25	50	100
24	ID1	10	20	20	20	30	30	10	20	40	0	0	0
25	IL1	2	15	70	12	20	75	5	25	70	3	15	35
26	IL10	8	12	16	8	12	16	10	15	20	15	25	35
27	IL11	10	20	30	7	10	14	4	8	12	5	9	13
28	IL12	5	10	15	10	30	50	10	20	30	5	10	15
29	IL2	5	10	15	10	15	20	5	10	15	5	10	15
30	IL3	8	15	20	8	15	20	2	5	10	5	10	15
31	IL4	3	5	10	5	10	15	3	5	10	10	20	25
32	IL5	2	6	15	2	8	20	3	8	12	3	8	20
33	IL6	5	12	20	5	10	15	5	10	15	10	15	25
34	IL7	5	10	15	10	15	25	0	5	10	10	20	30
35	IL8	2	4	6	3	5	7	8	10	12	5	10	15
36	IL9	5	10	15	10	15	20	5	10	15	5	10	15
37	IN1	4	10	20	2	8	15	3	6	10	5	9	16
38	IN2	2	3	5	2	3	8	1	3	5	1	2	6
39	IN3	3	8	12	2	5	10	3	9	15	5	15	20
40	IN4	5	15	25	15	25	40	5	10	15	5	10	15
41	IN5	10	15	25	7	10	15	8	12	20	15	25	30
42	KY1	2	5	10	10	20	30	10	25	50	2	5	10
43	KY2	5	10	20	3	8	12	5	10	15	5	10	15

Note: Mi, Mo, and Se represent minor, moderate, and severe field conditions, respectively.

No.	Respondent	Added Operations			Diverted Supervision			Leraning Curve			Errors & Omissions		
		Mi	Mo	Se	Mi	Mo	Se	Mi	Mo	Se	Mi	Mo	Se
44	MA1	5	8	20	3	10	20	3	8	17	0	5	10
45	MA2	5	10	20	5	10	20	5	10	20	5	10	20
46	MD1	5	10	20	3	5	10	5	10	20	5	10	20
47	MD2	5	14	20	5	7	9	6	12	20	5	8	15
48	MD3	3	6	9	4	7	10	5	9	12	8	12	20
49	MD4	5	14	26	6	16	26	9	20	38	7	18	39
50	MD5	5	14	20	5	7	9	6	12	20	5	8	15
51	ME1	5	10	15	5	10	15	5	10	15	5	10	15
52	MI1	3	10	15	3	10	15	1	6	10	6	12	18
53	MI2	5	20	50	0	15	50	3	20	50	0	15	75
54	MI3	0	5	20	5	10	25	5	10	25	5	10	25
55	MI4	2.5	5	12	5	10	17	2	5	5	2	5	10
56	MN1	2	5	15	4	10	25	4	15	20	3	10	25
57	MN2	5	10	25	1	2	5	0	5	10	0	3	10
58	MO1	3	6	13	5	10	15	4	11	18	3	9	15
59	MO2	5	10	25	10	20	50	5	10	15	5	10	15
60	MO3	20	50	60	10	20	40	5	20	40	5	20	40
61	MO4	5	10	15	10	20	30	10	20	30	3	8	12
62	MO5	2	5	10	2	4	8	3	5	12	2	5	13
63	MT1	10	15	25	5	15	30	10	15	20	5	15	30
64	NC1	2	6	10	5	10	15	5	8	12	3	10	25
65	NC2	5	12	20	8	17	30	8	15	40	5	12	20
66	ND1	2	5	10	2	5	12	1	2	4	2	5	10
67	NH1	3	6	10	5	10	10	5	10	15	0	5	10
68	NJ1	0	10	20	5	10	20	5	10	20	0	5	10
69	NV1	15	30	30	25	50	50	5	10	10	20	40	40
70	NY1	0	15	30	10	20	40	0	5	10	15	20	40
71	NY2	5	10	15	0	5	8	5	10	15	5	10	20
72	NY3	15	25	50	10	20	30	10	20	30	10	25	50
73	NY4	6	8	10	6	8	10	8	12	16	10	12	16
74	NY5	3	10	20	2	7	15	2	5	10	2	5	10
75	OH1	4	8	10	3	5	10	5	10	15	3	6	9
76	OH2	5	20	40	15	25	50	5	30	32	5	10	50
77	OH3	5	10	30	5	10	15	0	5	20	0	5	25
78	OH4	10	20	30	5	15	25	10	25	50	10	40	60
79	OH5	0	5	8	2	8	12	5	10	15	5	10	15
80	OH6	5	10	15	3	5	8	7	15	20	3	5	10
81	OH7	5	10	15	6	10	18	4	6	9	8	10	16
82	OH8	0	15	25	2	4	10	4	10	10	1	5	20
83	OH9	5	6	10	4	9	14	3	7	11	5	10	15
84	OR1	3	8	17	1	3	8	8	17	28	3	10	25
85	OR2	5	5	5	5	10	15	5	10	15	5	5	5
86	OR3	4	8	12	6	9	15	3	7	10	10	15	25

Note: Mi, Mo, and Se represent minor, moderate, and severe field conditions, respectively.

No.	Respondent	Added Operations			Diverted Supervision			Leraning Curve			Errors & Omissions		
		Mi	Mo	Se	Mi	Mo	Se	Mi	Mo	Se	Mi	Mo	Se
87	PA1	3	8	12	0	5	15	2	5	15	5	15	30
88	PA2	5	10	20	10	20	40	5	10	25	10	25	50
89	PA3	10	40	75	10	60	70	5	10	15	10	30	65
90	PA4	10	30	50	15	25	40	10	20	35	15	25	45
91	PA5	5	15	25	5	10	25	5	15	30	0	15	30
92	SC1	40	60	80	50	70	90	20	40	65	15	30	60
93	SC2	10	20	30	5	10	20	5	10	15	5	10	20
94	SC3	4	8	12	5	10	15	5	12	25	4	10	20
95	TN1	5.5	10	20	5	10	20	5	10	20	5	10	20
96	TN2	8.5	25	55	7.5	22.5	55	5	18.5	32.5	5	21	40
97	TN3	7	16	27	5	15	25	5	12	17	7	16	35
98	TX1	6	15	25	6	11	20	10	20	35	5	15	30
99	TX10	8	24	40	5	15	25	8	24	40	6	18	30
100	TX11	10	15	20	10	20	30	15	30	45	15	30	45
101	TX12	15	33	60	15	40	60	20	30	65	15	30	50
102	TX2	5	10	20	9	18	36	10	20	36	5	10	20
103	TX3	8	20	24	10	30	45	20	35	55	5	15	25
104	TX4	6	10	15	6	12	18	10	18	32	8	12	18
105	TX5	20	40	70	5	15	25	10	25	50	5	20	40
106	TX6	10	25	45	5	20	50	15	25	40	7	15	30
107	TX7	5	20	40	10	20	45	2	2	10	5	15	20
108	TX8	0	10	50	5	30	75	5	10	20	10	30	65
109	TX9	5	15	35	5	15	35	10	25	50	4	10	15
110	UT1	5	10	15	5	10	15	5	15	30	4	8	12
111	VA1	5	10	15	10	30	50	5	10	15	10	20	30
112	VA2	10	15	20	5	10	15	5	10	15	5	10	15
113	VA3	3	6	9	3	8	12	2	6	8	3	5	7
114	VA4	5	10	20	10	30	50	5	20	35	7	15	30
115	VA5	15	35	40	10	20	30	10	20	35	5	10	15
116	VA6	5	10	25	5	20	30	5	5	5	10	10	10
117	VA7	2	5	15	0	10	25	1	5	15	5	15	25
118	VT1	3	7	15	3	7	15	3	5	10	5	15	21
119	WA1	5	10	20	10	25	50	5	10	15	5	10	15
120	WA2	10	20	30	2	5	10	5	10	20	5	10	20
121	WA3	1	10	20	3	10	25	5	10	20	3	5	10
122	WI1	3	6	12	3	6	12	2	4	8	3	6	12
123	WI2	2	6	10	5	15	30	2	6	10	5	15	30
124	WI3	1	2	4	2	3	5	3	4	4	1	2	4
125	WI4	5	15	35	12	25	40	5	20	30	15	25	50
126	WI5	25	40	60	5	15	40	15	15	30	15	45	60
127	WI6	2	5	7	3	5	7	2	3	5	3	5	8
128	WV1	2	4	10	8	10	25	2	3	5	2	4	8
129	WY1	5	10	20	5	10	20	5	15	25	5	10	20

Note: Mi, Mo, and Se represent minor, moderate, and severe field conditions, respectively.

No.	Respondent	Beneficial Occupancy			Joint Occupancy			Site Access			Logistics		
		Mi	Mo	Se	Mi	Mo	Se	Mi	Mo	Se	Mi	Mo	Se
1	AL1	20	30	40	10	20	30	30	40	60	10	20	30
2	AZ1	8	20	20	5	17	30	10	20	20	6	10	25
3	AZ2	3	8	14	2	12	20	10	20	30	5	10	15
4	CA1	15	20	20	0	5	20	5	15	25	10	15	25
5	CA10	20	30	60	15	30	70	10	15	20	30	60	90
6	CA11	10	15	20	10	15	20	10	15	20	10	15	20
7	CA2	0	4	8	4	10	20	2	5	8	0	8	15
8	CA3	1	10	40	10	20	50	5	5	25	25	40	65
9	CA4	5	10	15	10	15	25	5	10	15	5	15	20
10	CA5	1	5	25	1	5	25	2	5	18	10	12	20
11	CA6	10	10	50	0	20	25	10	15	50	10	10	10
12	CA7	5	10	15	5	10	20	8	8	30	5	10	20
13	CA8	2	3	5	5	10	15	5	10	20	2	3	5
14	CA9	8	18	20	5	12	22	10	12	12	12	18	23
15	CO1	30	50	80	10	30	50	15	40	60	50	65	85
16	CO2	1	3	15	5	15	25	0	2	10	2	6	12
17	CO3	5	15	30	20	35	50	5	10	25	7	15	30
18	CO4	1	3	15	5	15	25	0	2	10	2	6	12
19	CT1	3	5	10	3	5	8	1	3	5	1	3	5
20	FL1	2	5	15	4	8	20	0	0	0	5	15	20
21	FL2	5	8	25	4	6	20	7	10	35	10	15	40
22	GA1	1	10	25	4	6	18	5	7	16	3	6	15
23	HI1	1	10	25	2	10	25	50	100	100	25	50	100
24	ID1	0	0	0	0	10	10	10	30	50	15	30	30
25	IL1	6	20	55	8	35	70	4	15	40	4	12	25
26	IL10	10	15	20	10	15	20	8	15	25	10	15	20
27	IL11	4	8	12	7	13	20	7	13	20	10	20	30
28	IL12	2	6	10	10	20	30	10	20	30	10	20	30
29	IL2	5	10	15	5	10	15	10	15	20	10	15	20
30	IL3	2	5	10	2	5	10	5	10	15	5	10	15
31	IL4	5	10	15	5	10	15	5	15	25	5	10	20
32	IL5	5	10	25	3	10	20	4	8	25	6	10	20
33	IL6	20	30	50	10	15	20	5	8	12	5	8	12
34	IL7	2	5	15	10	15	25	15	35	50	20	30	40
35	IL8	6	9	12	8	10	12	2	4	8	8	10	12
36	IL9	10	15	20	10	20	40	25	35	45	10	20	30
37	IN1	6	12	25	5	15	30	3	5	10	5	15	40
38	IN2	2	3	5	2	3	5	4	8	12	1	3	5
39	IN3	8	16	24	4	8	12	5	15	25	10	20	30
40	IN4	15	25	40	15	25	40	15	25	40	15	25	40
41	IN5	10	15	25	12	18	30	10	15	25	15	25	35
42	KY1	10	15	30	10	15	35	15	25	50	20	40	55
43	KY2	8	15	25	2	10	25	5	15	25	10	20	30

Note: Mi, Mo, and Se represent minor, moderate, and severe field conditions, respectively.

No.	Respondent	Beneficial Occupancy			Joint Occupancy			Site Access			Logistics		
		Mi	Mo	Se	Mi	Mo	Se	Mi	Mo	Se	Mi	Mo	Se
44	MA1	0	5	15	5	12	25	0	5	10	5	10	20
45	MA2	5	10	20	5	10	20	5	10	20	5	10	20
46	MD1	3	5	10	10	15	25	5	10	20	5	10	20
47	MD2	15	25	35	15	20	40	10	20	30	6	13	20
48	MD3	3	6	9	3	6	9	7	10	15	7	10	15
49	MD4	2	5	14	3	13	22	9	19	38	10	20	36
50	MD5	15	25	35	15	20	40	10	20	30	6	13	20
51	ME1	10	25	45	10	25	45	10	25	45	10	25	45
52	MI1	5	12	20	8	15	25	10	20	35	10	20	35
53	MI2	10	20	50	3	10	35	0	10	40	5	15	30
54	MI3	0	5	50	5	10	33	0	15	50	5	10	15
55	MI4	6	10	20	0	4	12	0	2	8	2	5	10
56	MN1	10	15	25	5	20	30	5	10	20	5	15	30
57	MN2	0	0	25	5	15	20	5	10	25	5	10	20
58	MO1	7	15	30	2	4	10	15	20	35	10	20	30
59	MO2	5	10	25	10	20	50	5	10	15	20	40	50
60	MO3	3	30	40	2	10	35	3	5	30	10	20	30
61	MO4	15	20	25	15	20	25	10	15	20	5	10	15
62	MO5	2	7	15	5	10	15	5	10	17	6	11	16
63	MT1	5	10	15	10	20	35	10	15	30	15	20	40
64	NC1	20	25	50	5	10	25	20	25	50	5	10	20
65	NC2	3	8	12	5	12	20	6	14	26	3	15	35
66	ND1	2	5	15	3	5	10	3	3	10	2	5	10
67	NH1	0	10	20	5	10	20	5	15	30	10	20	30
68	NJ1	0	5	20	5	10	20	5	10	20	5	10	20
69	NV1	2	25	25	0	0	0	25	30	30	10	25	75
70	NY1	5	10	20	5	10	20	15	25	35	15	25	35
71	NY2	3	8	15	3	8	15	5	10	25	5	10	25
72	NY3	10	20	40	10	20	30	15	25	50	10	20	40
73	NY4	18	24	30	10	15	20	10	15	20	10	15	20
74	NY5	3	10	20	2	7	15	2	7	15	3	10	20
75	OH1	5	10	15	5	10	15	5	10	15	4	8	10
76	OH2	5	10	70	10	25	35	20	30	30	20	40	70
77	OH3	0	0	10	0	0	20	10	20	40	20	30	40
78	OH4	10	20	30	10	25	40	15	30	50	10	20	30
79	OH5	2	6	10	2	6	10	2	6	10	5	10	15
80	OH6	3	5	8	2	5	7	5	10	12	5	10	12
81	OH7	8	15	25	10	18	25	10	20	30	8	10	15
82	OH8	0	5	20	5	9	48	8	15	45	0	0	0
83	OH9	2	5	10	4	7	16	5	10	15	3	7	11
84	OR1	2	4	15	0	5	25	2	5	15	10	20	30
85	OR2	5	5	5	10	15	25	15	20	25	5	5	5
86	OR3	15	25	30	12	20	25	15	25	30	5	12	22

Note: Mi, Mo, and Se represent minor, moderate, and severe field conditions, respectively.

No.	Respondent	Beneficial Occupancy			Joint Occupancy			Site Access			Logistics		
		Mi	Mo	Se	Mi	Mo	Se	Mi	Mo	Se	Mi	Mo	Se
87	PA1	2	5	15	3	8	10	7	12	25	9	15	28
88	PA2	10	25	50	10	25	50	0	20	30	5	15	25
89	PA3	10	50	50	5	25	50	10	50	85	10	50	60
90	PA4	10	15	20	5	15	35	10	20	40	20	40	60
91	PA5	30	100	100	5	10	20	10	20	50	50	100	100
92	SC1	10	30	50	10	30	50	20	50	65	10	15	20
93	SC2	10	20	30	15	25	35	10	20	30	10	20	30
94	SC3	8	16	30	7	15	30	6	10	18	5	15	25
95	TN1	5	10	20	5	10	20	5	10	20	5	10	20
96	TN2	7.5	25	65	5	17.5	37.5	7.5	27.5	55	12.5	32.5	72.5
97	TN3	6	25	40	11	22	40	8	17	35	10	20	45
98	TX1	10	25	40	10	20	35	8	25	40	8	18	33
99	TX10	3	9	15	6	18	30	6	18	30	6	18	30
100	TX11	20	40	60	15	20	25	5	15	20	10	20	30
101	TX12	10	15	33	15	25	50	5	15	75	5	15	25
102	TX2	10	20	30	10	20	30	15	25	35	10	20	30
103	TX3	18	30	42	15	20	34	25	35	50	10	22	40
104	TX4	15	25	40	10	16	22	15	24	33	10	16	24
105	TX5	5	10	30	10	15	40	20	30	40	10	20	40
106	TX6	15	25	45	12	30	40	8	15	35	10	25	45
107	TX7	1	5	10	15	20	25	5	10	20	10	20	30
108	TX8	10	50	80	5	20	60	5	20	80	10	30	70
109	TX9	15	25	75	3	12	20	5	18	40	4	14	35
110	UT1	4	8	12	5	12	25	5	12	25	5	12	25
111	VA1	20	40	60	10	20	30	20	40	60	20	40	60
112	VA2	10	20	30	10	20	30	5	10	15	20	30	40
113	VA3	7	8	15	3	6	8	5	10	15	2	6	8
114	VA4	20	40	60	5	15	45	15	30	50	10	30	50
115	VA5	15	25	35	10	20	30	15	30	45	15	30	45
116	VA6	0	25	35	15	30	40	10	25	45	10	25	45
117	VA7	10	25	40	10	15	25	0	5	20	1	5	10
118	VT1	3	15	21	3	7	15	5	15	21	7	20	25
119	WA1	10	25	50	10	25	50	10	20	30	10	25	50
120	WA2	1	3	5	2	5	10	5	10	20	5	10	20
121	WA3	5	10	20	10	20	50	15	20	40	5	10	25
122	WI1	4	8	16	4	8	16	4	8	16	4	8	16
123	WI2	5	15	35	5	15	30	5	15	30	5	15	30
124	WI3	1	1	1	2	3	4	2	3	4	1	2	2
125	WI4	20	45	62.5	20	30	62.5	10	25	35	15	30	60
126	WI5	5	15	40	15	25	40	15	25	40	10	20	40
127	WI6	3	5	8	2	5	8	2	5	7	5	10	15
128	WV1	0	8	10	0	3	10	10	15	20	3	6	10
129	WY1	3	10	25	10	15	25	10	15	25	10	15	25

Note: Mi, Mo, and Se represent minor, moderate, and severe field conditions, respectively.

No.	Respondent	Fatigue			Work Sequence			Overtime			Weather		
		Mi	Mo	Se	Mi	Mo	Se	Mi	Mo	Se	Mi	Mo	Se
1	AL1	30	40	60	20	30	40	30	40	60	10	20	30
2	AZ1	15	25	35	5	23	40	6	20	35	10	15	25
3	AZ2	5	7	19	2	4	6	10	25	35	2	10	30
4	CA1	5	7	7	0	0	10	5	12	15	0	7	20
5	CA10	5	10	15	40	60	80	10	20	30	15	30	50
6	CA11	8	12	15	5	10	15	8	12	16	8	12	16
7	CA2	0	5	10	5	15	25	5	15	25	2	5	15
8	CA3	10	20	25	10	25	60	10	20	25	5	10	25
9	CA4	5	10	15	5	10	15	10	15	25	5	10	10
10	CA5	4	7	13	3	10	20	10	20	30	10	15	28
11	CA6	10	20	40	5	10	20	5	10	20	0	5	15
12	CA7	5	10	15	5	10	30	5	10	20	0	5	10
13	CA8	2	3	5	5	10	20	5	15	25	5	10	15
14	CA9	5	8	12	5	8	12	15	25	35	10	15	15
15	CO1	15	30	80	15	20	50	20	30	60	20	40	50
16	CO2	4	10	40	2	10	20	2	10	20	2	5	10
17	CO3	5	10	20	5	10	15	2	15	30	0	3	7
18	CO4	4	10	40	2	10	20	2	10	20	2	5	10
19	CT1	1	2	5	2	5	10	2	5	10	5	10	15
20	FL1	2	5	10	5	10	20	5	10	20	2	4	6
21	FL2	4	10	25	5	9	20	10	15	25	7	10	20
22	GA1	4	7	15	5	12	24	1	4	10	0	3	10
23	HI1	5	10	20	3	6	9	5	10	20	1	5	15
24	ID1	0	0	0	20	40	60	0	10	20	10	20	40
25	IL1	2	14	40	5	15	40	3	25	80	2	15	40
26	IL10	10	15	20	8	15	18	8	15	18	20	30	40
27	IL11	4	8	12	7	13	20	7	13	20	7	13	20
28	IL12	5	10	15	5	10	15	10	20	30	10	20	30
29	IL2	5	10	15	5	10	15	5	10	15	10	15	20
30	IL3	5	10	15	5	10	15	2	5	10	2	5	15
31	IL4	3	5	10	3	5	10	5	10	15	5	15	35
32	IL5	3	8	20	2	5	20	10	15	25	5	10	20
33	IL6	10	15	25	10	20	30	10	20	30	10	25	50
34	IL7	20	25	30	15	25	35	0	0	10	0	5	10
35	IL8	4	6	8	3	6	9	5	10	20	2	10	25
36	IL9	5	10	15	10	20	30	5	15	25	0	15	20
37	IN1	6	15	30	6	10	20	10	15	50	5	10	20
38	IN2	2	4	6	5	10	18	1	5	10	0	3	12
39	IN3	15	25	35	10	20	30	4	12	25	5	15	25
40	IN4	10	20	30	10	20	30	10	20	30	10	25	45
41	IN5	5	10	15	10	20	30	5	10	15	8	20	25
42	KY1	5	8	15	10	25	55	15	25	40	0	5	10
43	KY2	8	14	25	10	15	20	15	25	35	10	15	25

Note: Mi, Mo, and Se represent minor, moderate, and severe field conditions, respectively.

No.	Respondent	Fatigue			Work Sequence			Overtime			Weather		
		Mi	Mo	Se	Mi	Mo	Se	Mi	Mo	Se	Mi	Mo	Se
44	MA1	10	15	20	3	8	17	5	12	25	3	8	17
45	MA2	5	10	20	5	10	20	5	10	20	5	10	20
46	MD1	5	10	20	3	5	10	10	20	30	5	10	20
47	MD2	8	10	20	9	14	20	10	15	21	8	15	25
48	MD3	3	6	9	3	6	9	3	6	9	5	7	10
49	MD4	8	20	37	7	17	44	7	13	25	8	19	32
50	MD5	8	10	20	9	14	20	10	15	21	8	15	25
51	ME1	5	10	15	5	20	45	5	10	20	10	20	30
52	MI1	15	30	40	3	10	15	15	25	35	15	20	30
53	MI2	0	5	30	2	10	30	10	15	25	0	10	15
54	MI3	0	10	20	5	15	33	5	10	25	0	10	25
55	MI4	0	2	4	2	5	15	3	7	14	0	5	10
56	MN1	1	5	10	5	15	25	1	10	15	10	10	20
57	MN2	0	1	5	0	2	8	0	5	10	0	0	5
58	MO1	3	6	9	8	11	20	10	30	35	15	20	25
59	MO2	10	20	30	5	10	15	10	20	30	10	20	30
60	MO3	5	10	20	5	25	40	5	25	40	5	15	40
61	MO4	10	20	30	5	10	15	10	20	30	10	20	30
62	MO5	2	4	10	4	9	15	3	7	10	3	10	15
63	MT1	5	15	20	10	15	30	5	10	15	5	10	15
64	NC1	5	8	15	2	10	20	2	5	20	5	10	20
65	NC2	3	8	12	6	14	26	3	8	12	5	12	20
66	ND1	1	2	4	3	5	10	1	5	15	0	2	5
67	NH1	5	15	20	5	10	15	0	5	15	5	10	15
68	NJ1	0	5	10	0	5	10	5	10	20	5	10	20
69	NV1	0	0	0	10	30	60	2	15	25	2	25	40
70	NY1	0	5	10	10	20	45	5	10	15	15	25	50
71	NY2	3	8	15	3	8	15	5	10	15	5	15	30
72	NY3	10	20	30	15	25	50	10	20	40	15	25	50
73	NY4	12	18	24	10	15	20	15	20	25	15	20	25
74	NY5	3	10	20	2	7	15	2	7	15	3	10	20
75	OH1	2	5	9	3	5	9	3	6	9	3	6	12
76	OH2	5	10	30	20	35	70	20	40	60	20	45	85
77	OH3	0	15	25	5	15	30	0	5	20	0	5	15
78	OH4	10	25	50	15	30	45	10	25	50	5	50	80
79	OH5	2	6	10	2	6	10	5	10	15	5	10	15
80	OH6	2	5	7	2	5	7	2	5	8	3	7	10
81	OH7	4	6	8	6	9	12	8	12	18	10	15	20
82	OH8	1	5	12	1	4	10	0	15	30	2	15	16
83	OH9	2	5	10	4	8	16	4	10	18	5	10	15
84	OR1	10	20	40	5	18	35	5	20	35	10	40	100
85	OR2	5	10	15	0	5	5	0	5	10	15	20	37.5
86	OR3	5	15	23	10	15	20	5	15	23	10	15	25

Note: Mi, Mo, and Se represent minor, moderate, and severe field conditions, respectively.

No.	Respondent	Fatigue			Work Sequence			Overtime			Weather		
		Mi	Mo	Se	Mi	Mo	Se	Mi	Mo	Se	Mi	Mo	Se
87	PA1	5	8	15	5	12	25	5	15	25	3	11	15
88	PA2	5	15	25	10	25	50	10	25	50	5	10	20
89	PA3	5	30	35	10	40	60	5	10	15	15	50	75
90	PA4	5	15	20	10	20	35	5	10	15	10	15	20
91	PA5	15	30	50	10	20	40	0	10	25	0	10	30
92	SC1	15	30	60	15	30	60	20	30	40	15	30	45
93	SC2	20	30	40	10	20	35	10	20	40	5	10	15
94	SC3	10	20	30	4	20	30	8	22	40	3	10	20
95	TN1	5	10	20	5	10	20	5	10	20	5	10	20
96	TN2	5	13.5	25	5	21	35	5	15	30	7.5	22.5	50
97	TN3	5	13	20	6	15	22	7	17	27	7	16	27
98	TX1	7	21	35	5	15	30	15	25	35	5	15	25
99	TX10	8	24	40	8	24	40	8	24	40	5	15	25
100	TX11	15	25	35	10	20	30	15	30	45	15	30	45
101	TX12	10	30	50	10	25	30	20	33	50	15	20	40
102	TX2	10	20	30	12	16	32	10	20	30	10	20	30
103	TX3	10	25	35	15	35	45	10	25	40	8	15	25
104	TX4	8	14	22	12	20	30	15	25	40	12	19	26
105	TX5	10	20	30	10	30	40	15	30	50	10	25	40
106	TX6	10	20	25	5	15	35	10	25	50	5	15	30
107	TX7	2	10	20	10	20	30	2	10	20	2	10	15
108	TX8	20	60	100	5	20	40	0	10	30	10	15	40
109	TX9	4	9	20	15	35	60	12	30	50	3	8	15
110	UT1	5	15	30	5	10	15	5	12	25	5	15	30
111	VA1	5	10	15	15	30	45	5	10	15	5	10	20
112	VA2	5	10	15	10	15	20	10	20	35	20	30	40
113	VA3	3	8	10	5	8	12	3	6	9	2	7	10
114	VA4	20	40	80	5	15	50	20	50	80	1	3	10
115	VA5	15	35	45	15	35	40	15	35	45	15	25	35
116	VA6	5	5	5	10	15	25	10	20	25	10	10	15
117	VA7	2	5	20	2	10	20	10	15	20	10	25	40
118	VT1	3	7	15	3	10	15	5	15	20	5	10	15
119	WA1	10	20	30	10	25	50	10	15	20	3	8	17
120	WA2	2	5	10	2	5	10	5	15	30	5	10	20
121	WA3	2	15	25	2	10	20	5	15	20	2	10	20
122	WI1	3	6	12	3	6	12	4	8	16	4	8	16
123	WI2	2	6	10	2	6	10	3	8	13	10	25	60
124	WI3	2	3	4	1	3	5	1	2	3	1	4	15
125	WI4	20	40	67.5	15	25	40	15	30	50	15	25	50
126	WI5	10	20	40	10	20	40	10	10	30	20	40	60
127	WI6	3	5	8	5	8	10	5	10	12	2	5	8
128	WV1	2	5	8	5	8	10	4	8	12	0	2	2
129	WY1	10	15	25	10	15	25	10	20	25	10	20	25

Note: Mi, Mo, and Se represent minor, moderate, and severe field conditions, respectively.

Appendix D Summary of Significant Facts of the Validation Projects

Project 1: Parking Garage

- A total masonry cost of approximately $1,000,000
- Completed within budget and on-time
- Below-average change orders and average rework requested by the owner
- Similar design as a previous project
- Not enough skilled personnel with high absence of the masonry workers
- Worked with plumbing and electrical workers in the same area at least once a week (congestion)
- Difficult to access brick storage due to other trades working around that area (site access)
- Crew composition: 10 bricklayers, 15 bricklayer helpers, 2 forklift operators, and 1 superintendent

Project 2: Office Building

- A total masonry cost of approximately $1,000,000
- Ongoing work and likely to be on-time and within budget
- Below-average change orders and average rework requested by the owner
- Redesigned with an amendment at short notice
- Partially occupied for an adjoining building (joint occupancy)
- Encountered change orders resulting in change in work sequence (work sequence)

Project 2: Office Building (Cont'd)

- Crew composition: 10 bricklayers, 15 bricklayer helpers, 2 forklift operators, and 1 superintendent

Project 3: Parking Garage

- A total masonry cost of approximately $1,100,000
- Completed within budget and on-time
- Average change orders and below-average rework requested by the owner
- Obtained addenda with significant change in design
- Other trades working in the same area at least once a week (congestion)
- Crew composition: 10 bricklayers, 15 bricklayer helpers, 2 forklift operators, and 1 superintendent

Project 4: School Building

- A total masonry cost of approximately $3,000,000
- Ongoing work and likely to be over-budget and delayed
- Above-average change orders and rework requested by the owner
- Complex masonry work, large amount of detail
- Incomplete and poor set of document and drawings (errors and omissions)
- Lack of answers to RFI's (diverted supervision)

Project 4: School Building (Cont'd)

- Experienced owner's negative attitude toward the masonry contract (morale and attitude)
- Crew composition: 14 bricklayers, 14 bricklayer helpers, 4 machine operators, and 3 superintendents

Project 5: Student Dormitory

- A total masonry cost of approximately $2,600,000
- Completed within budget, but delayed
- Below-average change orders and average rework requested by the owner
- Under-cover working condition
- Worked with steel and plumbing workers in the same area (congestion)
- Crew composition: 14 bricklayers and 16 bricklayer helpers

Appendix E Summary of Distributed and Returned Questionnaires

No.	State	Questionnaires Distributed	Questionnaires Responded	Total Reponses (%)	Valid Responses	Valid Responses (%)
		(a)	(b)	(b)/(a) x 100	(c)	(c)/(b) x 100
1	AL	7	1	14%	1	100%
2	AR	1	0	0%	0	-
3	AZ	9	2	22%	2	100%
4	CA	187	15	8%	11	73%
5	CO	18	5	28%	4	80%
6	CT	12	1	8%	1	100%
7	DE	2	0	0%	0	-
8	FL	13	3	23%	2	67%
9	GA	9	1	11%	1	100%
10	HI	1	1	100%	1	100%
11	IA	6	1	17%	0	0%
12	ID	1	1	100%	1	100%
13	IL	123	14	11%	12	86%
14	IN	22	5	23%	5	100%
15	KS	4	0	0%	0	-
16	KY	15	3	20%	2	67%
17	LA	2	1	50%	0	0%
18	MA	6	3	50%	2	67%
19	MD	17	5	29%	5	100%
20	ME	2	1	50%	1	100%
21	MI	29	6	21%	4	67%
22	MN	11	2	18%	2	100%
23	MO	76	6	8%	5	83%
24	MS	3	0	0%	0	-
25	MT	3	1	33%	1	100%
26	NC	19	2	11%	2	100%
27	ND	1	0	0%	0	-
28	NE	5	2	40%	1	50%
29	NH	3	1	33%	1	100%
30	NJ	4	1	25%	1	100%
31	NM	1	0	0%	0	-
32	NV	11	1	9%	1	100%
33	NY	14	5	36%	5	100%
34	OH	76	9	12%	9	100%
35	OK	1	0	0%	0	-
36	OR	12	3	25%	3	100%
37	PA	25	7	28%	5	71%
38	SC	6	3	50%	3	100%
39	SD	1	0	0%	0	-
40	TN	12	3	25%	3	100%
41	TX	92	15	16%	12	80%
42	UT	5	2	40%	1	50%
43	VA	21	7	33%	7	100%
44	VT	5	1	20%	1	100%
45	WA	26	3	12%	3	100%
46	WI	27	7	26%	6	86%
47	WV	1	1	100%	1	100%
48	WY	3	1	33%	1	100%
	TOTAL	**950**	**152**	**16%**	**129**	**85%**

Appendix F Summary of Data Analyses Results

Summary of Analysis Results from the Model Development Process AFTER Eliminating Outliers

Statistics		Congestion			Morale and Attitude			Labor Reassignment		
		Minor	Moderate	Severe	Minor	Moderate	Severe	Minor	Moderate	Severe
N	Valid	112	110	114	94	113	112	112	113	113
	Missing	4	6	2	22	3	4	4	3	3
Mean		5	12	24	4	12	21	5	12	21
Std. Error of Mean		0.27	0.55	1.12	0.21	0.70	1.13	0.30	0.60	1.07
Median		5	10	20	5	10	20	5	10	20
Mode		5	10	20	5	10	20	5	10	20
Std. Deviation		2.91	5.79	11.92	2.03	7.40	11.93	3.14	6.35	11.41
1.96 x (SE)		0.54	1.08	2.19	0.41	1.36	2.21	0.58	1.17	2.10
Mean-1.96x(SE)		4.57	11.18	22.28	3.31	10.81	18.53	4.11	10.52	19.38
Mean+1.96x(SE)		5.65	13.34	26.65	4.13	13.54	22.95	5.27	12.86	23.59
Variance		8.47	33.49	142.11	4.13	54.71	142.21	9.84	40.38	130.09
Skewness		0.45	0.56	0.87	-0.29	0.81	0.70	0.67	0.76	0.87
Std. Error of Skewness		0.23	0.23	0.23	0.25	0.23	0.23	0.23	0.23	0.23
Kurtosis		-0.62	-0.39	0.04	-0.29	0.02	0.03	0.03	-0.34	0.21
Std. Error of Kurtosis		0.45	0.46	0.45	0.49	0.45	0.45	0.45	0.45	0.45
Range		10	23	45	9	30	55	15	28	48
Minimum		0	2	5	0	0	0	0	2	2
Maximum		10	25	50	9	30	55	15	30	50
Sum		572.5	1348.5	2789	349.5	1376	2323	525	1321	2428
Percentiles	10	2	5	10	0	5	8	1	5	10
	25	3	8	15	2	7	12	2	6.5	12
	50	5	10	20	5	10	20	5	10	20
	75	6	15	30	5	15	30	5.75	15	30
	90	10	20	50	5	25	40	10	20	40

Statistics		Crew Size Change			Added Operations			Diverted Supervision		
		Minor	Moderate	Severe	Minor	Moderate	Severe	Minor	Moderate	Severe
N	Valid	115	110	113	95	112	108	115	114	112
	Missing	1	6	3	21	4	8	1	2	4
Mean		5	11	20	4	11	18	6	13	22
Std. Error of Mean		0.34	0.50	1.00	0.19	0.51	0.80	0.32	0.66	1.22
Median		5	10	20	5	10	16	5	10	20
Mode		5	10	20	5	10	20	5	10	15
Std. Deviation		3.61	5.26	10.66	1.89	5.35	8.29	3.40	7.07	12.88
1.96 x (SE)		0.66	0.98	1.97	0.38	0.99	1.56	0.62	1.30	2.38
Mean-1.96x(SE)		4.47	9.67	18.02	3.37	9.57	16.54	4.93	11.34	20.00
Mean+1.96x(SE)		5.80	11.64	21.96	4.13	11.55	19.66	6.17	13.93	24.77
Variance		13.06	27.71	113.74	3.56	28.63	68.65	11.56	50.00	165.79
Skewness		0.62	0.84	1.01	-0.08	0.91	0.71	0.65	0.80	0.91
Std. Error of Skewness		0.23	0.23	0.23	0.25	0.23	0.23	0.23	0.23	0.23
Kurtosis		-0.16	0.14	0.89	0.37	0.41	0.20	0.01	-0.12	-0.10
Std. Error of Kurtosis		0.45	0.46	0.45	0.49	0.45	0.46	0.45	0.45	0.45
Range		15	22	45	10	23	36	15	28	50
Minimum		0	3	5	0	2	4	0	2	5
Maximum		15	25	50	10	25	40	15	30	55
Sum		590.5	1172	2259	356	1183	1955	638.5	1440.5	2507
Percentiles	10	0	5	8	1	5	9	2	5	9
	25	2	6.75	11	2	6	11.25	3	8	12
	50	5	10	20	5	10	15.5	5	10	20
	75	8	15	25	5	15	24.75	8	18	30
	90	10	20	33	5	20	30	10	25	45

Statistics		Learning Curve			Errors and Omissions			Beneficial Occupancy		
		Minor	Moderate	Severe	Minor	Moderate	Severe	Minor	Moderate	Severe
N	Valid	98	114	110	97	114	110	116	115	114
	Missing	18	2	6	19	2	6	0	1	2
Mean		4	11	18	4	11	19	7	14	25
Std. Error of Mean		0.21	0.57	0.96	0.19	0.55	0.91	0.51	0.83	1.32
Median		5	10	15	5	10	15	5	10	20
Mode		5	10	15	5	10	15	10	10	15
Std. Deviation		2.04	6.13	10.10	1.88	5.84	9.57	5.50	8.93	14.14
1.96 x (SE)		0.40	1.13	1.89	0.37	1.07	1.79	1.00	1.63	2.59
Mean-1.96x(SE)		3.59	9.87	16.18	3.42	9.67	16.94	5.64	11.91	22.15
Mean+1.96x(SE)		4.39	12.12	19.96	4.17	11.82	20.52	7.64	15.17	27.34
Variance		4.18	37.63	101.97	3.54	34.16	91.65	30.20	79.76	199.80
Skewness		0.06	0.80	0.99	-0.48	0.86	0.86	0.93	0.86	0.84
Std. Error of Skewness		0.24	0.23	0.23	0.24	0.23	0.23	0.22	0.23	0.23
Kurtosis		-0.20	-0.25	0.45	-0.50	0.26	0.14	0.05	0.27	0.01
Std. Error of Kurtosis		0.48	0.45	0.46	0.49	0.45	0.46	0.45	0.45	0.45
Range		9	23	46	8	23	41	20	40	61.5
Minimum		0	2	4	0	2	4	0	0	1
Maximum		9	25	50	8	25	45	20	40	63
Sum		391	1253.5	1987.5	368	1225	2060	770.5	1557	2820.5
Percentiles	10	1	4.5	6.2	1	5	8.1	1	5	10
	25	2	6	10	2.5	5	10	2	6	15
	50	5	10	15	5	10	15	5	10	20
	75	5	15	20.25	5	15	25	10	20	31.25
	90	6.1	20	35	5	20	34.5	15	25	50

Statistics		Joint Occupancy			Site Access			Logistics		
		Minor	Moderate	Severe	Minor	Moderate	Severe	Minor	Moderate	Severe
N	Valid	116	116	114	111	112	116	108	111	116
	Missing	0	0	2	5	4	0	8	5	0
Mean		7	14	25	7	14	27	7	15	26
Std. Error of Mean		0.41	0.66	1.06	0.41	0.68	1.20	0.35	0.67	1.30
Median		5	15	25	5	15	25	6	15	25
Mode		10	15	20	5	10	20	10	10	20
Std. Deviation		4.43	7.09	11.27	4.28	7.24	12.96	3.62	7.10	14.02
1.96 x (SE)		0.81	1.29	2.07	0.80	1.34	2.36	0.68	1.32	2.55
Mean-1.96x(SE)		6.02	12.69	23.14	6.12	12.73	24.33	6.32	13.35	23.93
Mean+1.96x(SE)		7.63	15.27	27.28	7.71	15.41	29.05	7.69	15.99	29.03
Variance		19.62	50.26	127.07	18.34	52.47	167.83	13.08	50.44	196.58
Skewness		0.66	0.57	0.44	0.41	0.33	0.40	0.27	0.45	0.78
Std. Error of Skewness		0.22	0.22	0.23	0.23	0.23	0.22	0.23	0.23	0.22
Kurtosis		0.01	0.22	-0.32	-0.52	-0.60	-0.52	-0.50	-0.26	0.66
Std. Error of Kurtosis		0.45	0.45	0.45	0.46	0.45	0.45	0.46	0.46	0.45
Range		20	35	46	15	30	60	15	32.5	72.5
Minimum		0	0	4	0	0	0	0	0	0
Maximum		20	35	50	15	30	60	15	33	73
Sum		792	1621.5	2873.5	767.5	1575.5	3096	756.5	1628.5	3071.5
Percentiles	10	2	5	10	2	5	10	2	6	10
	25	3	9.25	19.5	5	10	16.25	5	10	15.25
	50	5	15	25	5	15	25	6	15	25
	75	10	20	30.75	10	20	35	10	20	35
	90	12.9	22.9	40	15	25	46.5	10	25	45

Statistics		Fatigue			Work Sequence			Overtime		
		Minor	Moderate	Severe	Minor	Moderate	Severe	Minor	Moderate	Severe
N	Valid	112	111	114	116	116	113	115	115	114
	Missing	4	5	2	0	0	3	1	1	2
Mean		5	11	20	6	14	23	7	15	24
Std. Error of Mean		0.35	0.59	1.00	0.36	0.70	1.10	0.39	0.69	1.06
Median		5	10	20	5	10	20	5	15	22
Mode		5	10	20	5	10	20	5	10	20
Std. Deviation		3.70	6.25	10.63	3.84	7.51	11.74	4.16	7.36	11.31
1.96 x (SE)		0.68	1.16	1.95	0.70	1.37	2.16	0.76	1.35	2.08
Mean-1.96x(SE)		4.64	10.08	18.04	5.41	12.23	20.99	5.87	13.38	22.39
Mean+1.96x(SE)		6.01	12.40	21.94	6.81	14.96	25.31	7.39	16.07	26.54
Variance		13.66	39.05	113.09	14.73	56.36	137.81	17.32	54.24	127.91
Skewness		0.82	0.66	0.61	0.74	0.86	0.63	0.45	0.47	0.64
Std. Error of Skewness		0.23	0.23	0.23	0.22	0.22	0.23	0.23	0.23	0.23
Kurtosis		0.23	-0.49	-0.37	-0.12	0.38	-0.51	-0.58	-0.46	-0.25
Std. Error of Kurtosis		0.45	0.46	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Range		15	24	46	15	35	45	15	35	47
Minimum		0	1	4	0	0	5	0	0	3
Maximum		15	25	50	15	35	50	15	35	50
Sum		596	1247.5	2279	709	1577	2616	762	1693	2789
Percentiles	10	1	5	8	2	5	10	1.6	5	10
	25	2.25	6	10	3	8.25	15	4	10	15
	50	5	10	20	5	10	20	5	15	22
	75	8	15	26.25	10	20	30	10	20	30
	90	10	20	36	10	25	40	13.2	25	40

Statistics		Weather or Environment		
		Minor	Moderate	Severe
N	Valid	116	111	113
	Missing	0	5	3
Mean		6	12	22
Std. Error of Mean		0.43	0.59	1.02
Median		5	10	20
Mode		5	10	20
Std. Deviation		4.65	6.25	10.88
1.96 x (SE)		0.85	1.16	2.01
Mean-1.96x(SE)		5.17	11.13	20.11
Mean+1.96x(SE)		6.86	13.46	24.13
Variance		21.64	39.12	118.47
Skewness		0.77	0.43	0.85
Std. Error of Skewness		0.22	0.23	0.23
Kurtosis		0.22	-0.50	0.39
Std. Error of Kurtosis		0.45	0.46	0.45
Range		20	25	48
Minimum		0	0	2
Maximum		20	25	50
Sum		697.5	1364.5	2499.5
Percentiles	10	0	5	10
	25	2	8	15
	50	5	10	20
	75	10	15	27.5
	90	12.9	20	40

Summary of Analysis Results from the Model Development Process BEFORE Eliminating Outliers

No.	Field Factors	Estimated Percentage of Productivity Loss (%), If the Factor Is … *(0% to 100% in each column)*		
		Minor	**Moderate**	**Severe**
1	Congestion	**6** 0-25	**13** 2-35	**26** 5-65
2	Morale and Attitude	**5** 0-28	**13** 0-35	**22** 0-70
3	Labor Reassignment	**5** 0-15	**12** 2-40	**22** 2-65
4	Crew Size Change	**5** 0-25	**12** 3-50	**21** 5-80
5	Added Operations	**5** 0-20	**12** 2-50	**22** 4-70
6	Diverted Supervision:	**6** 0-30	**13** 2-40	**25** 5-75
7	Learning Curve	**5** 0-20	**12** 2-35	**20** 4-70
8	Errors and Omissions	**5** 0-15	**11** 2-40	**21** 4-75
9	Beneficial Occupancy	**7** 0-20	**14** 0-45	**26** 1-75
10	Joint Occupancy	**7** 0-20	**14** 0-35	**26** 4-70
11	Site Access	**8** 0-25	**15** 0-40	**28** 0-75
12	Logistics	**8** 0-20	**16** 0-40	**27** 0-72
13	Fatigue	**6** 0-20	**12** 1-40	**21** 4-80
14	Work Sequence	**6** 0-20	**14** 0-35	**25** 5-70
15	Overtime	**7** 0-20	**15** 0-50	**26** 3-80
16	Weather or Environment	**6** 0-20	**13** 0-50	**24** 2-100

Note: This table presents low, mean, and high percentages of productivity loss from the raw data.

Summary of Analysis Results from the Model Validation Process

Statistics		PROJECT1	PROJECT2	PROJECT3	PROJECT4	PROJECT5
N	Valid	114	116	110	114	112
	Missing	2	0	6	2	4
Mean		10.60	27.57	12.26	38.18	5.11
Std. Error of Mean		0.58	1.17	0.55	1.71	0.27
Median		10	25	10	35	5
Mode		10	20	10	35	5
Std. Deviation		6.23	12.60	5.79	18.30	2.91
1.96 x (SE)		1.14	2.29	1.08	3.36	0.54
Mean-1.96x(SE)		9.5	25.3	11.2	34.8	4.6
Mean+1.96x(SE)		11.7	29.9	13.3	41.5	5.7
Variance		38.77	158.69	33.49	334.96	8.47
Skewness		0.59	0.41	0.56	0.70	0.45
Std. Error of Skewness		0.23	0.22	0.23	0.23	0.23
Range		28	50	23	85	10
Minimum		0	5	2	5	0
Maximum		28	55	25	90	10
Sum		1208	3198.5	1348.5	4352	572.5
Percentiles	10	3	13	5	18	2
	25	6	16.25	8	23.75	3
	50	10	25	10	35	5
	75	15	36	15	50	6
	90	20	45	20	65	10

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